Chapter 3. WHAT THE STUDY HAS REVEALED OR CONFIRMED

When the San Joaquin Valley Drainage Program was initiated in late 1984, there were many questions and conflicting opinions about westside San Joaquin Valley drainage and drainage-related problems. Through Program-supported studies from 1985 to 1990, some questions have been answered, some myths discredited, and some controversy resolved; but other questions and issues remain. The drainage problem was a long time developing. It will likely be solved only through the diligence and cooperation of many individuals and organizations over a considerable period. Further study will undoubtedly be essential to these efforts.

A common base of knowledge is paramount to understanding the causes and for developing potential solutions to drainage problems. This chapter describes major advancements in knowledge of various aspects of the drainage problem.

GEOHYDROLOGY

Understanding the geologic makeup and hydrologic characteristics of the study area is necessary to understanding the cause of the drainage problem.

Geology

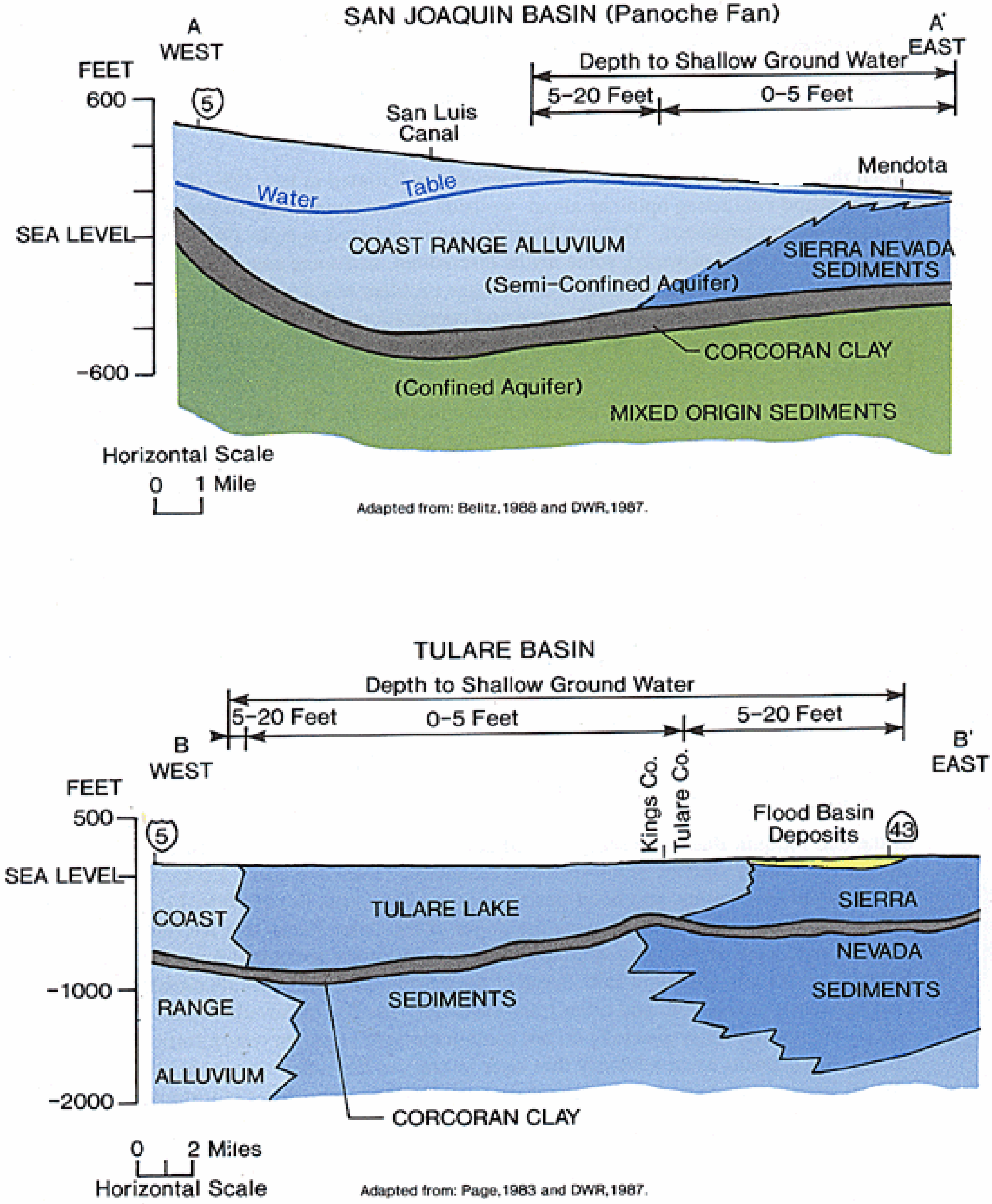
The Corcoran Clay, a clay layer 20 to 200 feet thick that underlies all but a small part of the study area, was formed as a lakebed about 600,000 years ago and is an important geologic feature of the San Joaquin Valley (Figure 4). Lying as much as 850 feet deep along the Coast Ranges and 200 to 500 feet deep in the valley trough, the Corcoran Clay effectively divides the ground-water system into two major aquifers — a confined aquifer below it and a semiconfined aquifer above it (Page, 1986).

In the San Joaquin Basin, the semiconfined aquifer can be divided into three geohydrologic units, based on the sources of the soils and sediments. These are Coast Range alluvium, Sierra Nevada sediments, and flood-basin deposits. The Coast Range alluvial deposits, which range in thickness from 850 feet along the slopes of the Coast Range to a few feet along the valley trough, were derived largely from the erosion of marine rocks that form the Coast Ranges and contain abundant salt. Some of the marine sediments contain elevated concentrations of selenium and other trace elements. The Sierra Nevada sediments on the eastern side of the valley generally do not contain elevated selenium concentrations. The flood-basin deposits are a relatively thin layer in areas of the valley trough that have been created in recent geologic time. These three geohydrologic units differ in texture, hydrologic properties, chemical characteristics, and oxidation state.

Figure 4

GENERALIZED GEOHYDROLOGICAL CROSS-SECTIONS IN THE SAN JOAQUIN AND TULARE BASINS

(Locations Shown in Figure 6)



Adapted from: Belitz, 1988 and DWR, 1987.

Adapted from: Page, 1983 and DWR, 1987.

In the Tulare Basin, the semiconfined aquifer consists of the same three geohydrologic units found in the San Joaquin Basin, plus one additional unit, Tulare Lake sediments. The Tulare Basin is characterized by the presence of several dry lakebeds, including Tulare, Buena Vista, and Kern.

The marine sediments from which most soils in the study area are derived contain salts and potentially toxic trace elements, such as arsenic, boron, molybdenum, and selenium. When these soils are irrigated, the substances dissolve and leach into the shallow ground water (Gilliom, et al., 1989a). Selenium is largely a westside phenomenon. Soils derived from Coast Range sediments are generally far saltier than soils formed from Sierran sediments. In fact, selenium in livestock feed grown in some areas of the eastern side of the valley is so low that it must be added to the livestock diet. Figure 5 shows selenium in the top 12 inches of soil, as determined by a survey in the mid-1980s. Most soluble selenium has been leached from the soils over the past 30 to 40 years, and it now occurs in solution in the shallow ground water. It is drained from there when growers attempt to protect crop roots from salts and a high water table. Generally, growers need not be concerned about protecting crops from selenium.

Surface Water

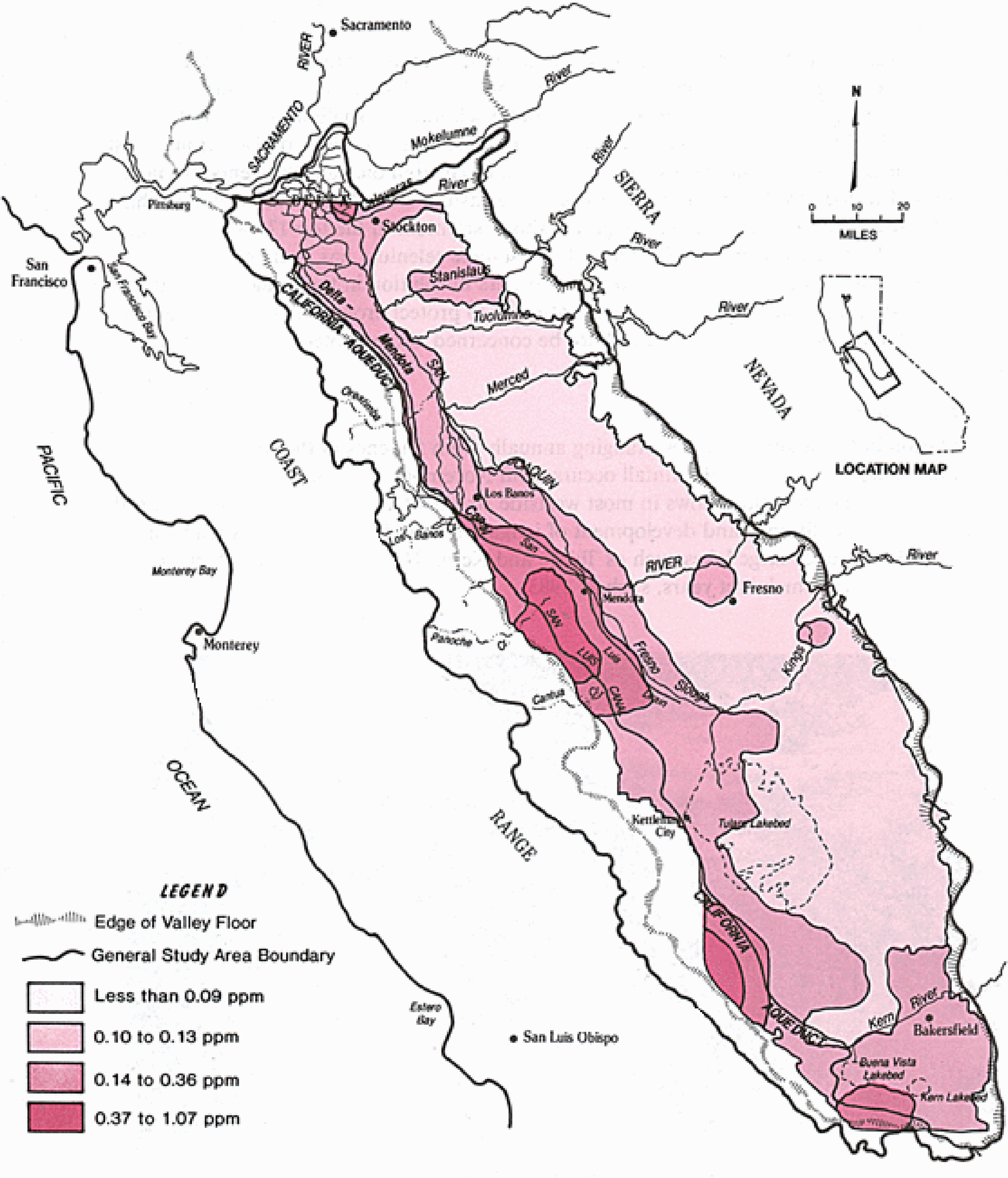
Precipitation in the study area is low, ranging annually from 5 inches in the south to 10 inches in the north. Virtually all rainfall occurs from November through April, and, by midsummer, the small natural flows in most westside streams have ended or dwindled to little more than trickles. Storage and development of irrigation facilities on eastside streams have reduced inflow to once-large lakes such as Tulare and Kern. Now water reaches their dry lakebeds only in extremely wet years, such as 1983.

Natural vegetation growing on the westside San Joaquin Valley without irrigation.

Figure 5

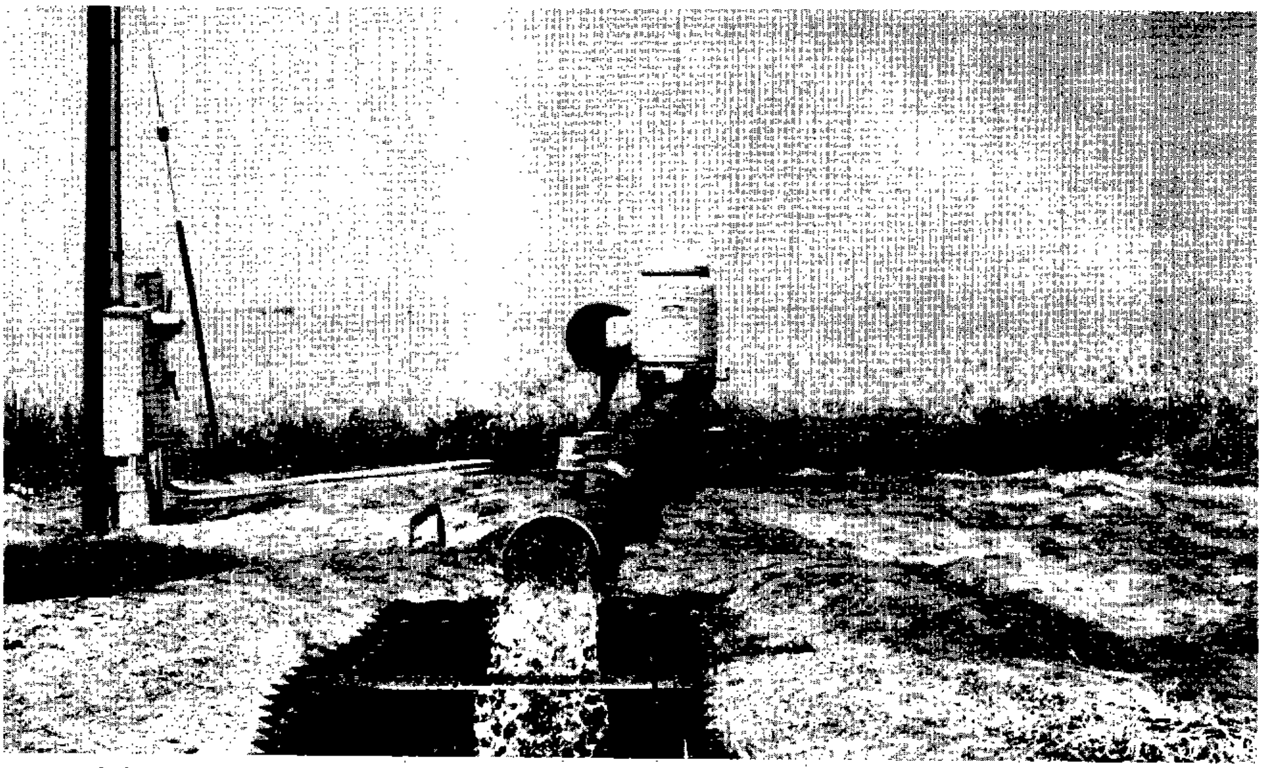
SELENIUM CONCENTRATIONS IN SOILS

(Total Selenium in Top 12 Inches of Soil)



Adapted from Tidball et. al., 1986

The San Joaquin River and its major westside tributaries, Salt Slough and Mud Slough, are important to the study area because they convey drainage water away from the Northern and Grasslands subareas. San Joaquin River flows are controlled by dams on tributaries and on the main stem upstream from Fresno. Water stored in Millerton Reservoir is diverted through the Friant-Kern and Madera canals. Irrigation water historically diverted from the lower reaches of the San Joaquin River was replaced with Central Valley Project water provided through the Delta-Mendota Canal, beginning in 1951. Now, the San Joaquin River is essentially dry much of the year from below Gravelly Ford to the point at which irrigation return flow and local runoff replenish the river. Development on major eastside tributaries has also reduced the flow of the San Joaquin River. The combination of these actions causes problems in water quantity and quality, both for fish and for other downstream river users, especially in the South Delta area.



Irrigation water is still pumped from both above and below the Corcoran Clay, especially during drought periods when surface water supplies are short.

Ground Water

Pumping of ground water for irrigation from 1920 to 1950 drew ground-water levels down as much as 200 feet in large portions of the study area (Belitz, 1988). High pumping costs, land subsidence, and declining water quality created a need for new water supplies. By 1951, Federal Central Valley Project water was being pumped from the Delta and delivered to the Northern and Grasslands subareas through the Delta-Mendota Canal. By 1968, water was being delivered to the Westlands, Tulare, and Kern subareas through facilities of the CVP's San Luis Unit and the State Water Project.

With a reliable supply of surface water, ground-water pumping for irrigation lessened and the ground-water reservoir gradually began to refill. The semiconfined aquifer above the Corcoran Clay is now fully saturated in much of the westside area. Water tables continue to rise, and the waterlogged area is expanding. During the period 1977-1987, the 0-to-5-foot area expanded from 533,000 acres to 817,000 acres (W.C. Swain, 1990a). Figure 6 shows areas in which the water table was less than 5 feet deep, 5 to 10 feet deep, and 10 to 20 feet deep during part of 1987.

Irrigation-induced leaching of the soil and accumulation of salts from both the leaching and from imported water have concentrated dissolved salts in the upper portion of the semiconfined aquifer. Most of these salts are now located in a zone 20 to 150 feet below the ground surface (DuBrovsky and Neil, 1990). Ground-water quality is generally better above and below this zone. Figures 7 through 11 show concentrations of salinity, selenium, boron, molybdenum, and arsenic in shallow ground water (less than 20 feet below the land surface). This shallow ground water, and, in some places, water located even deeper, is the source of subsurface drainage water.

There are still zones in the semiconfined aquifer above the Corcoran Clay in which ground water is present in quality and quantity suitable for irrigation. Figure 12 shows the location of zones with salinity less than 1,250 parts per million (ppm) for several aquifer thicknesses saturated with water of that quality. The map was prepared by using a geographic information system and combining and evaluating water quality data and well construction information for the study area, as obtained from the U.S. Geological Survey, the U.S. Bureau of Reclamation, the Department of Water Resources, the Central Valley Regional Water Quality Control Board, and local water agencies. The procedures used were designed to produce a conservative estimate of the total depth of ground water that meets the specific water quality criterion of 1,250 parts per million total dissolved solids. Lenses of good quality water (less than 1,250 ppm TDS) overlying poor quality water (more than 1,250 ppm TDS) were not included in the total depth calculations. In some areas, notably in the southern Westlands Subarea, data from studies conducted in the 1960s were used in the absence of more recent data. Elsewhere, data from 1970 to 1989 predominated (Quinn, 1990).

DRAINAGE-WATER CONSTITUENTS

Salinity

Drainage water contains dissolved mineral substances often referred to as "salts." These salts include sulfates, chlorides, carbonates, and bicarbonates of the elements sodium, calcium, magnesium, and potassium. The term "salinity" refers to the salt content of solutions containing dissolved mineral salts, which is commonly measured as either total dissolved solids (TDS) in parts per million (ppm) or electrical conductivity (EC) in microsiemens per centimeter (μS/cm). There are three sources of salts in the study area: (1) Water imported from the Sacramento-San Joaquin Delta; (2) soils; and (3) ground water. The imported water is of generally good quality; that is, its average salinity is less than 350 ppm. But because of the large volume of such water, about 1,600,000 tons[1] of salts are imported per year (D.G. Swain, 1990).

1 Calculated by: Firm water supply imported annually (3,400,000 acre-feet) x salinity (350 ppm TDS) x conversion factor (0.00136) = 1,620,000 tons.

Figure 6
AREAS OF SHALLOW GROUND WATER 1987

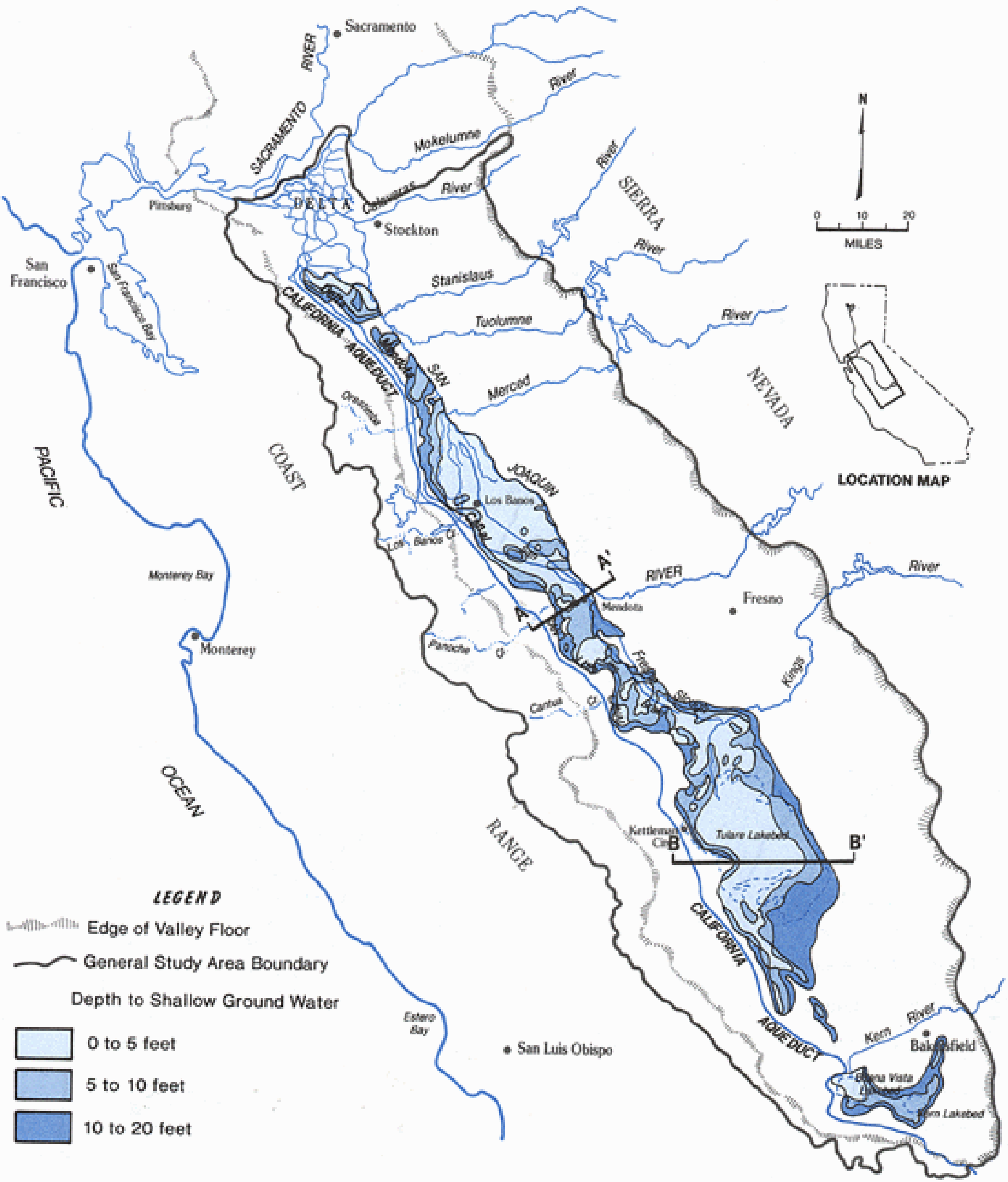


Figure 7

SALINITY IN SHALLOW GROUND WATER
Sampled between 1984 and 1989

(Measured as Electrical Conductivity in microsiemens per centimeter [µS/cm]).

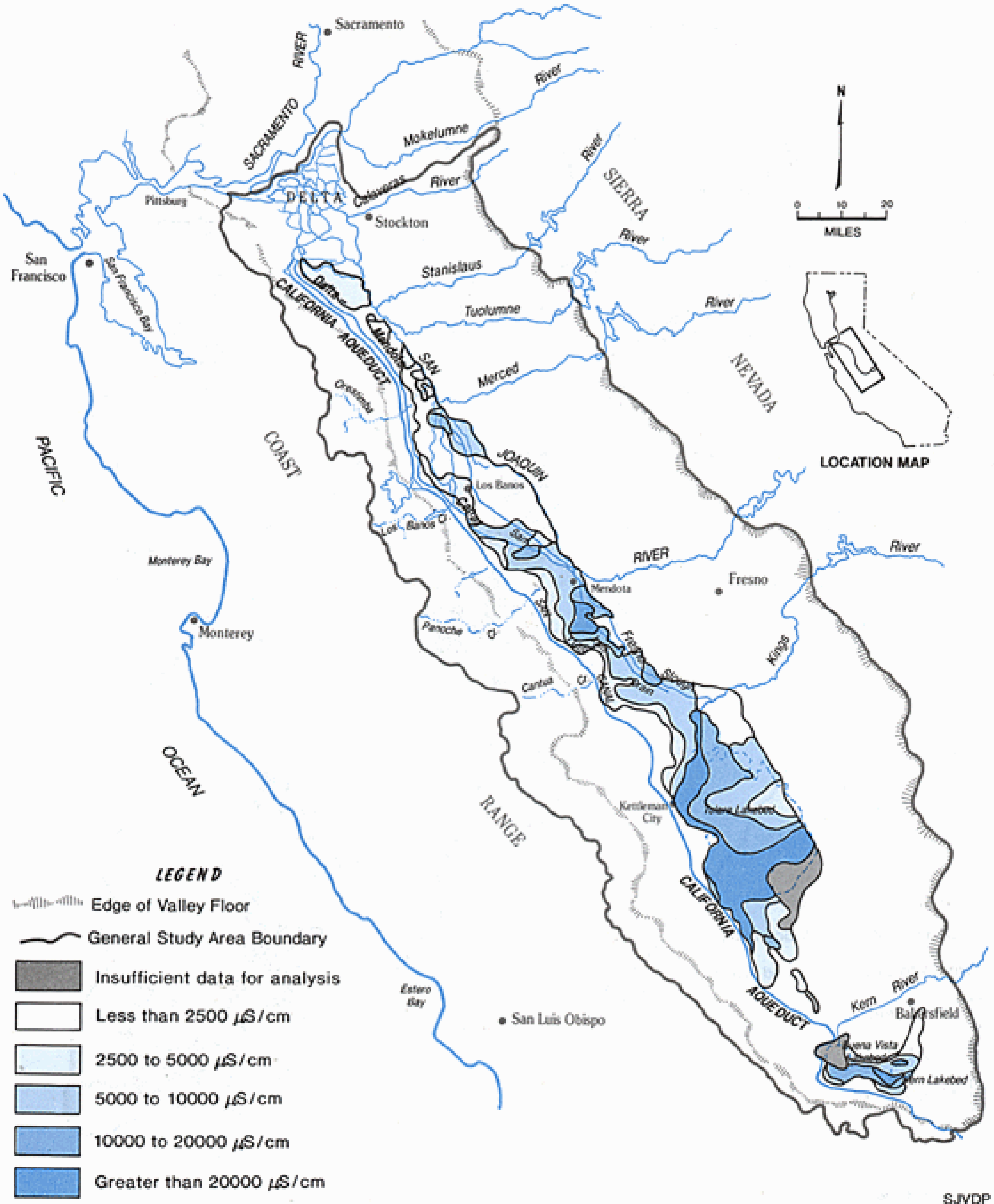


Figure 8

SELENIUM CONCENTRATIONS IN SHALLOW GROUND WATER
Sampled between 1984 and 1989

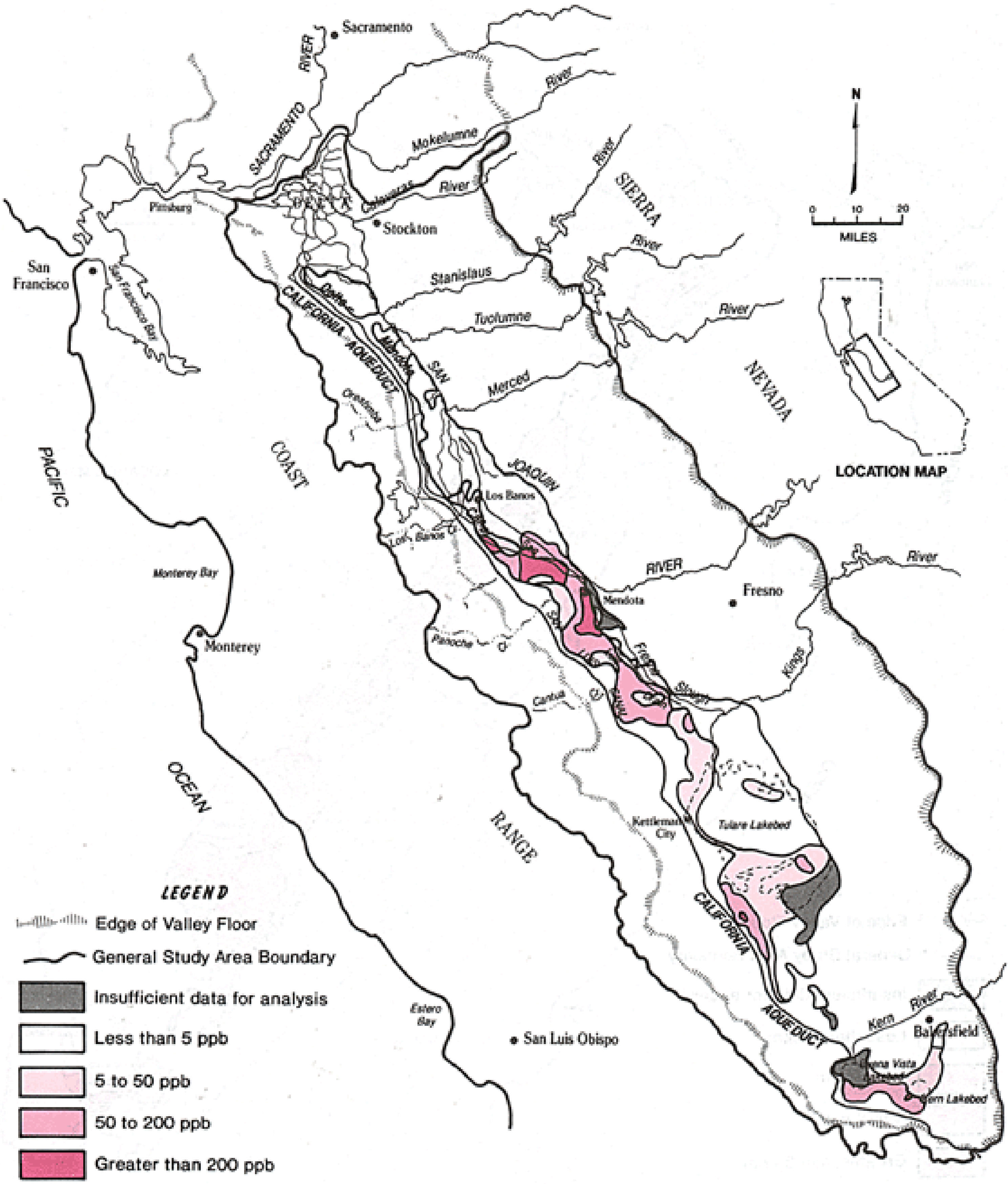


Figure 9

BORON CONCENTRATIONS IN SHALLOW GROUND WATER
Sampled between 1984 and 1989

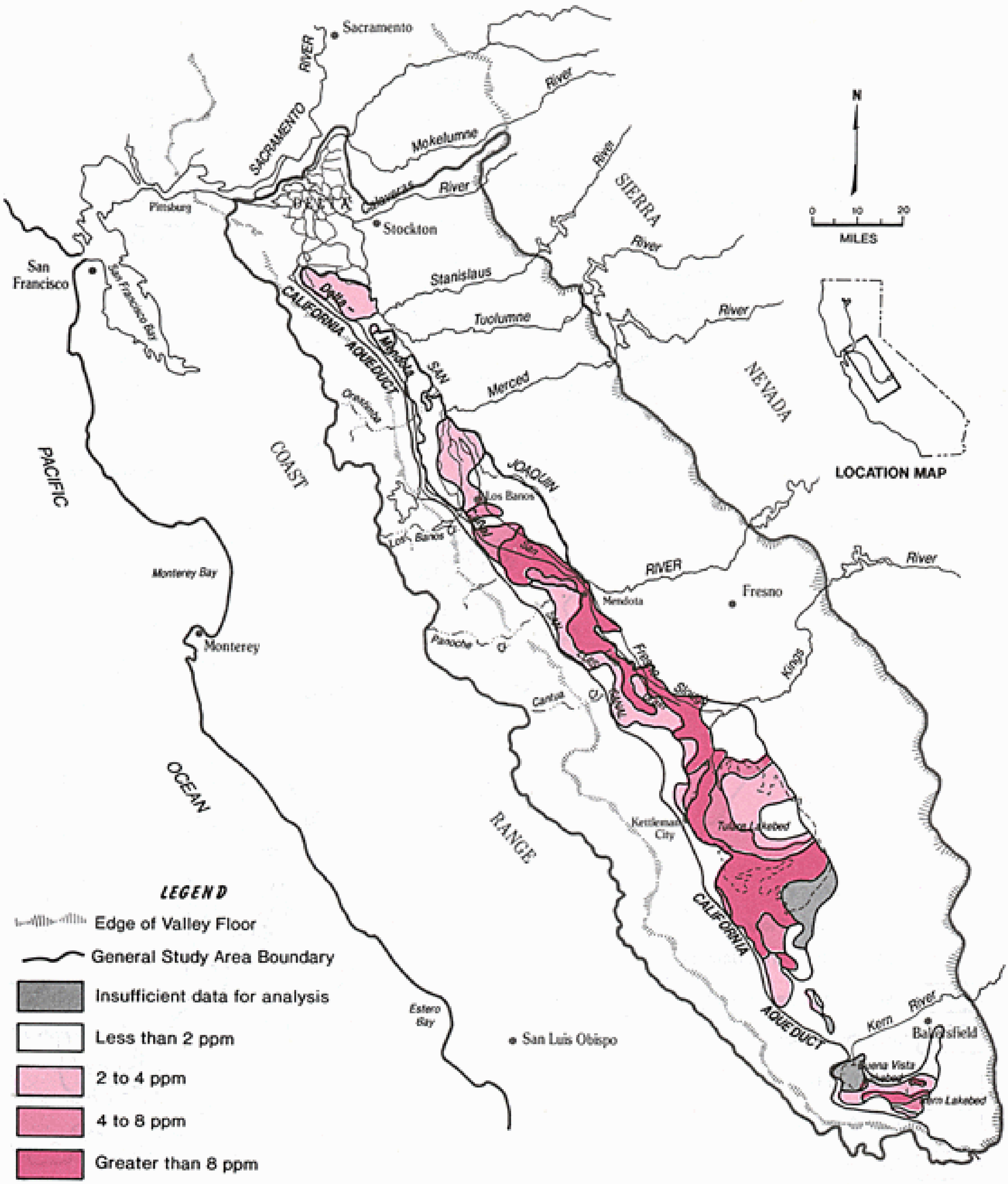


Figure 10

MOLYBDENUM CONCENTRATIONS IN SHALLOW GROUND WATER
Sampled between 1984 and 1989

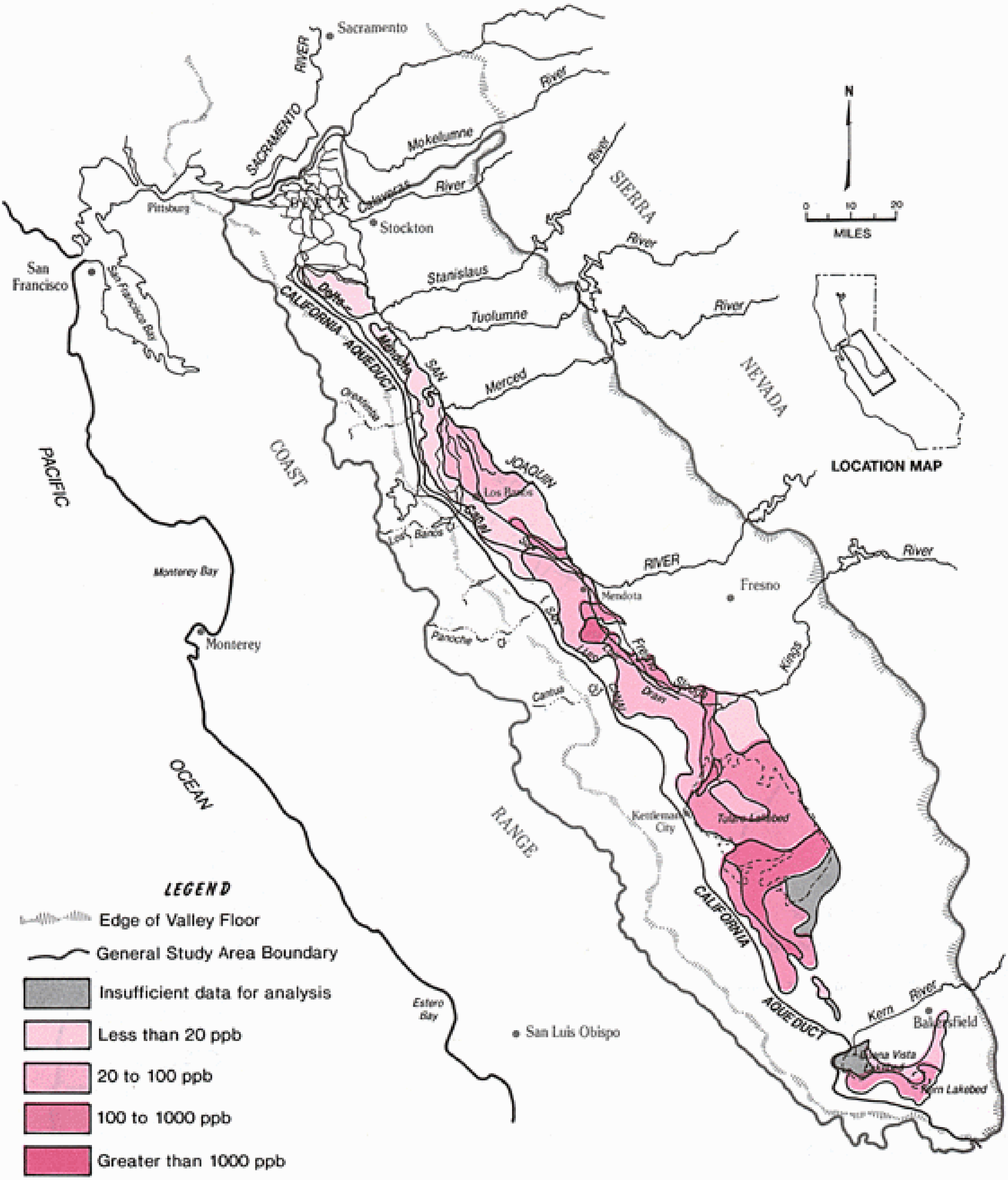


Figure 11

ARSENIC CONCENTRATIONS IN SHALLOW GROUND WATER
Sampled between 1984 and 1989

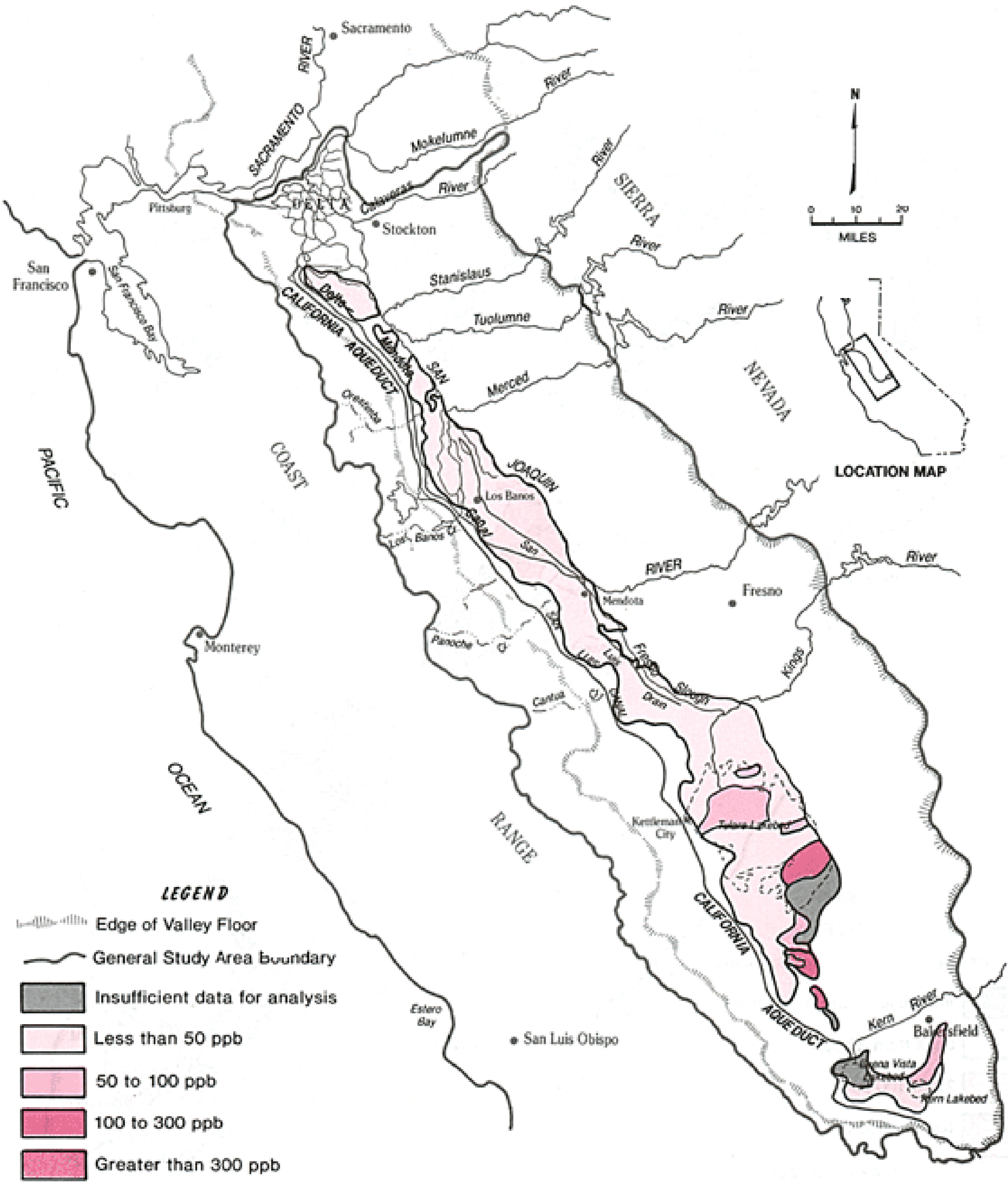
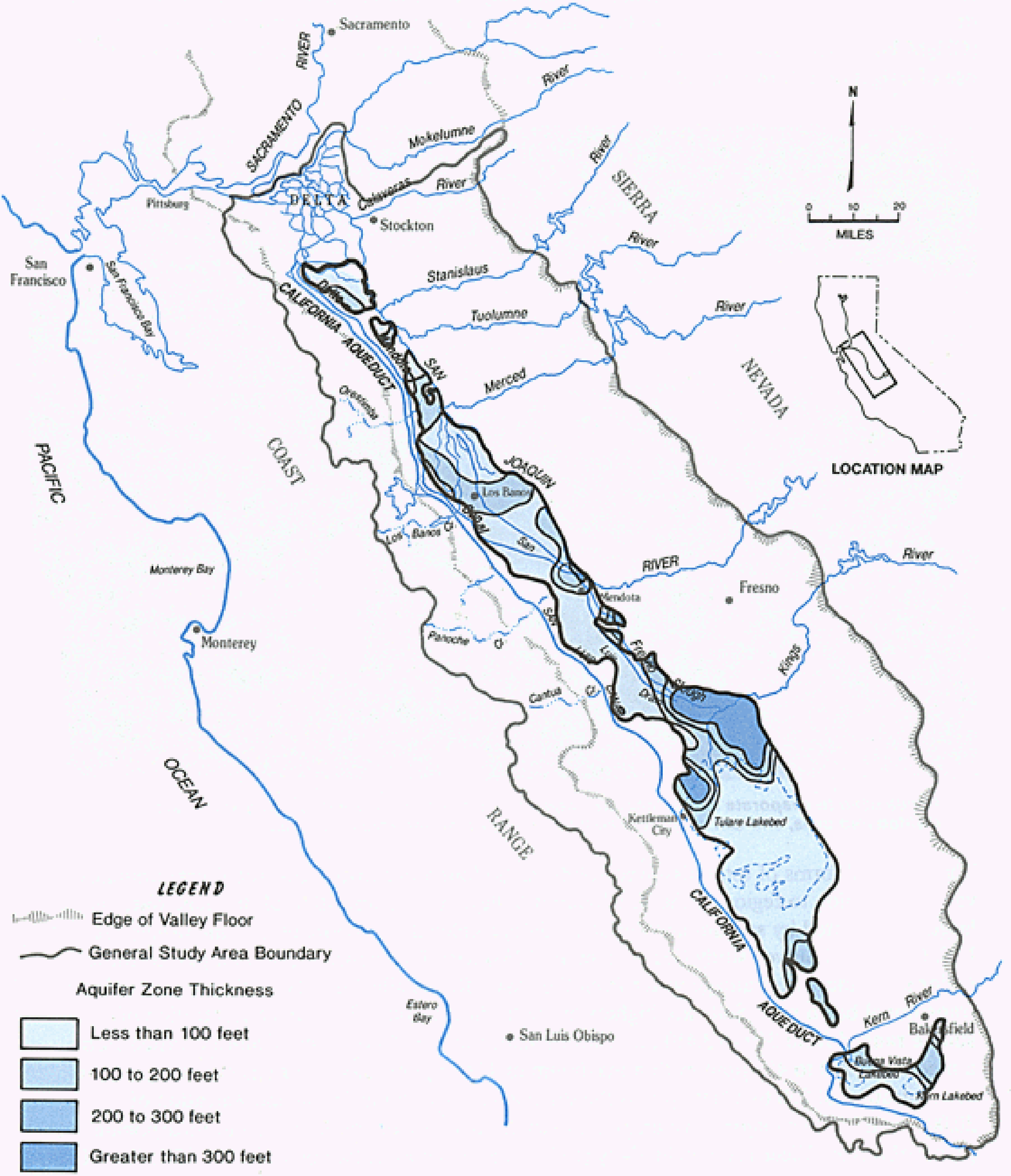


Figure 12

AQUIFER ZONES ABOVE THE CORCORAN CLAY WITH LESS THAN 1,250 ppm TOTAL DISSOLVED SOLIDS (Sampled between 1960 and 1989)



LEGEND

Edge of Valley Floor

General Study Area Boundary

Aquifer Zone Thickness

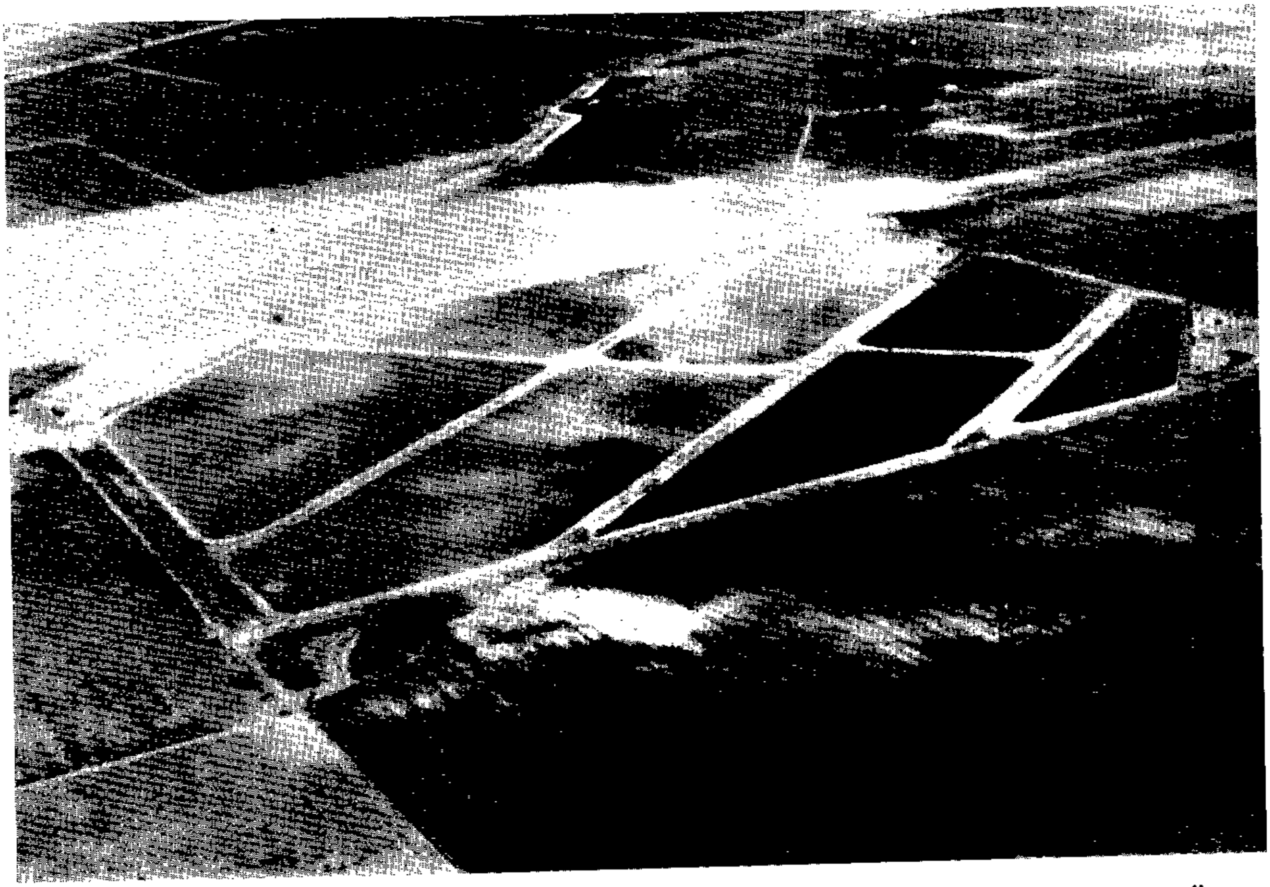
Less than 100 feet

100 to 200 feet

200 to 300 feet

Greater than 300 feet

A buildup of salts in the soil can adversely affect agricultural productivity. The arid soils on the westside San Joaquin Valley contain substantial amounts of naturally acquired soluble salts that can leach into the ground water below the root zone. These salts contribute heavily to the salinity of the soil solution and, subsequently, to the drainage water, if a field is drained. About half the soluble salts in the crop root zone are derived from the soil (CH_2M Hill, 1988). Evapotranspiration increases the concentration of salts in the soil, and use of irrigation return flows also further concentrates them.



Ponds used to evaporate subsurface drainage water often cover several hundred acres, are generally divided into cells, and can evaporate about 4 feet of water per acre each year.

The chemical forms of total dissolved solids (salts) found in subsurface agricultural drainage vary from region to region in the San Joaquin Valley. The composition of drainage water is largely dominated by sodium and sulfate, although chloride is dominant in some places. A U.S. Geological Survey study (Deverel, et al., 1984) described concentration ranges for these major substances in drainage water from the Coast Range alluvium, the basin trough, and the transitional basin rim. Salts are highest in the basin rim zone. Median concentration of sulfate ranged from 310 to 3,450 ppm, with a maximum of 65,000 ppm. Chloride varied from a median of 220 to 455 ppm, with a maximum of 16,000 ppm. Sodium ranged from a median concentration of 230 to 1,100 ppm in the three zones, with a maximum concentration of 30,000 ppm. Other major substances are calcium, magnesium, potassium, and bicarbonate plus carbonate. Electrical conductivity (EC) ranges from a median of 1,900 to 6,055 µS/cm in the three zones, while the maximum observed value was 68,000 µS/cm. By comparison, the electrical conductivity of seawater is about 50,000 µS/cm.

High concentrations of nitrate with values greater than 70 ppm have also been observed in some areas. Nitrates are considered to have a dissolved salt source, although certain pollutant-type sources such as fertilizers and feedlots have also been documented. A potential public health hazard may exist if nitrates in public water supplies exceed 45 ppm. Nitrates and sulfates in drainage water also have been shown to hinder selenium removal in certain treatment processes (Hanna, et al., 1990).

Extensive sampling and analyses by Federal and State scientists during the period 1984-1989 have shown that pesticides are rarely detected in westside subsurface drainage water. However, pesticides have been observed in field irrigation runoff (tailwater), and commingling of tailwater and subsurface water does occur in parts of the valley (Gilliom and Clifton, 1987).

Evaporation ponds are one of the most common means to dispose of subsurface drainage water in the southern San Joaquin Valley. High salinity in the ponds, entering either from outside sources or developing from evaporation, produces concentrations of salts that may cause environmental problems. The dominant minerals (salts) in the evaporation ponds are typically sodium sulfate and sodium chloride, mainly due to the composition of geologic formations contributing to subsurface drainage systems. Inflow TDS concentrations were observed to range from 2,500 to 65,000 ppm in one study (CVRWQCB, 1988c). Concentrations in the ponds affected by evaporation have been measured as high as 388,000 ppm. (Seawater is about 31,000 ppm TDS.) During the evaporation-driven process of concentration, numerous physical, chemical, and biological processes affect the reactivity, solubility, and availability of trace element constituents in these high-salinity evaporation ponds (K.K. Tanji, in press).

Trace Elements

Toxic and potentially toxic trace elements occur naturally in some soils on the western side of the San Joaquin Valley, and they are leached into the shallow ground water during irrigation. These elements, originally found in the geologic formations of the Coast Ranges, can be mobilized, transported, and concentrated in irrigation drainage water. Another minor source of trace elements is imported irrigation water.

Over the past several years, many studies have evaluated the chemical composition of agricultural drainage water. These studies, conducted by government agencies and other researchers, have produced evidence of the existence of a large group of trace elements or chemical substances that may be found at elevated concentrations at some time or place in irrigation drainage water. This group of elements or chemical constituents, called "substances of concern," comprises 29 substances (Table 4). Basically, these substances are of concern in the environment because of their actual or possible adverse effects on water quality, public health, agricultural productivity, and/or fish and wildlife.

Table 4. SUBSTANCES OF CONCERN

Of Primary Concern	Of Probable Concern	Of Possible Concern	Of Possible Concern	Of Limited Concern	Probably Not of Concern at Present
	Subject to future California water-quality objectives	*Elevated concentrations at some sites*	*Little information available*	*Known toxic elements in low concentrations*	
Selenium Boron Molybdenum Arsenic Salts	Cadmium Chromium Copper Manganese Nickel Zinc	Uranium Vanadium Nitrates	Tellurium Antimony Lithium Germanium Bismuth Strontium Fluoride Beryllium	Lead Silver Mercury	Magnesium Iron Barium Aluminum

Criteria used by the Drainage Program as evidence of primary concern include these factors: (1) The substance has been cited in State/Federal water-quality regulations (there are water-quality criteria affecting its concentration, use, and distribution); (2) it is known to cause toxicity and create other problems for fish and wildlife; and (3) it can become hazardous to other wildlife and to humans by accumulating in the food chain or by direct exposure to contaminated soils, sediments, air, or ground water and surface water.

The trace elements of primary concern are selenium, boron, molybdenum, and arsenic, all of which occur naturally in westside soils. Arsenic is of concern primarily in the Tulare and Kern Subareas, where it has been observed in elevated concentrations in shallow ground water. In other locations, such as parts of Westlands Water District, concentrations of hexavalent chromium in shallow ground water have been observed above usual background levels. The State Water Resources Control Board and the Drainage Program have also identified salts as substances of primary concern.

In addition, other elements for which the State Board eventually may establish site-specific water-quality criteria are cadmium, copper, manganese, nickel, and zinc (SWRCB, 1987). Samples from some evaporation ponds have shown high concentrations of uranium. Elevated concentrations of vanadium have also been found in some evaporation ponds. Other substances have also been measured in ongoing monitoring programs. These include nitrates, tellurium, mercury, antimony, germanium, bismuth, strontium, fluoride, beryllium, lead, magnesium, iron, aluminum, lithium, silver, and barium. In some instances, there is not enough information on the effects of these elements to establish them as substances of primary concern, and in others, the concentrations are not high enough to establish a definite level of concern.

Selenium leads the four elements of primary concern, primarily because it is widely distributed in the study area and because of its proven and potential toxicity. Water and mudflows have transported the selenium to the valley in particulate and dissolved forms derived from the weathering and erosion of source rocks. Decades of irrigation have transferred soluble selenium from the upper soils to the shallow ground water, where its highest concentrations occur generally along the edge of the valley trough in the lower parts of the Coast Range alluvial fans.

Selenium concentrations in shallow ground water show a wide range of values. In the U.S. Geological Survey's study of three physiographic zones (Coast Range alluvium, the basin rim, and the basin trough) on the western side of the valley (Deverel, et al., 1984), values ranged from less than 1.0 part per billion (ppb) to 3,800 ppb, with a median concentration for all zones of 6.0 ppb. Water entering Kesterson Reservoir in the spring of 1984 had an average of 385 ppb. To protect freshwater aquatic life, the Environmental Protection Agency recently established ambient water-quality criteria for selenium — 5.0 ppb for chronic toxicity and 20 ppb for acute toxicity (USEPA, 1987). Saltwater limits are higher. The State Board has established a monthly mean objective for selenium of 5.0 ppb for a specific area of the San Joaquin River.

Evaporation ponds can accumulate and concentrate trace elements that may be hazardous to wildlife, especially waterfowl and shore birds that use the ponds. A study of 22 ponds by the Central Valley Regional Water Quality Control Board indicates that trace-element concentrations vary widely (CVRWQCB, 1988c). Each of the four primary substances of concern (selenium, boron, molybdenum, and arsenic) occurs in high concentrations in one or more of the ponds. Selenium, for example, in these 22 ponds ranges from less than 1.0 ppb to 1,900 ppb, with a median value of 17 ppb.

Elevated concentrations of boron (greater than 2.0 ppm) are found in parts of all the subareas under study, except the Northern Subarea. Although boron is essential to the nutrition of certain plants, concentrations in excess of 0.5 ppm are known to be harmful to some crops. For this reason, it is regarded primarily as an agricultural crop problem. The State Board established water-quality objectives for boron in the San Joaquin River that ranged from 0.8 to 1.3 ppm, depending on the time of year or whether it is a critically dry water year. The Regional Board's studies show that boron in evaporation ponds ranges from 2.5 to 840 ppm, with a median concentration of 20 ppm.

Molybdenum has been found in elevated concentrations (greater than 20 ppb) in various areas of the San Joaquin Valley, particularly in the Tulare and Kern subareas. Molybdenum in very low concentrations is essential to many plants and some mammal species. In high concentrations, it can be injurious to the growth of many kinds of plants. It can be toxic to livestock through bioaccumulation, particularly in ruminant animals (cattle and sheep). A technical committee of SWRCB recommended a 10-ppb criterion in water to protect agricultural uses. The EPA has not set any water-quality criteria for molybdenum. Molybdenum is an abundant element in evaporation ponds, ranging in concentration from 7.0 to 7,775 ppb at the inlets to the ponds and 58 to 40,000 ppb in the ponds. Few studies have been performed to assess the potential consequences of elevated dietary molybdenum in humans.

Arsenic is a known toxicant that has been shown to become concentrated at relatively high levels in evaporation ponds in the Tulare Basin. Arsenic values in evaporation ponds range from 2.0 to 900 ppb in the inlets to the ponds and 1.0 to 13,000 ppb in the ponds. Occurrences in other parts of the San Joaquin Valley are not as frequent, nor are the levels as high, on the average. Certain chemical forms of inorganic arsenic are suspected human carcinogens. The EPA has set 50 ppb as the current maximum contaminant level for arsenic compounds in drinking water and established 190 ppb as the water-quality criterion for freshwater aquatic life.

Uranium was not one of the elements of concern studied in earlier evaluations of drainage-water constituents. However, the presence of elevated concentrations of uranium in Tulare Basin evaporation ponds has been documented (CVRWQCB, 1988b). These ranged from 30 to 11,000 ppb in studies conducted in 1987-88. The mean concentration for all pond samples was 675 ppb, while the mean concentration in the inflow samples of the three basins studied was 280 ppb. Over 60 percent of the evaporation pond area exceeded a Canadian marine water-quality objective of 500 ppb uranium. At the present time, there is no information regarding the role uranium may play in the toxicity problems of the evaporation ponds. In 1988-89, the USGS studied the occurrence of uranium in shallow ground water in parts of the Tulare Subarea. Results have not yet been published.

The toxicity of drainage-water constituents is influenced by their chemical interaction with other substances. The understanding of these interactions is limited. In addition to the independent effects of trace elements, antagonistic or synergistic interactions may occur among various constituents.

The list of substances that may be of concern in drainage water is not final at this time. Certain other substances not now listed have occasionally been detected in drainage-water samples or in water influenced by subsurface drainage. Future studies and continued monitoring may produce data that will indicate whether certain chemicals not presently thought to be important will have to be more thoroughly appraised.

DRAINAGE-WATER TREATMENT AND REUSE

At the beginning of the Drainage Program, major effort was focused on treatment of drainage water to make it environmentally acceptable and/or reusable. Selenium became the principal concern in those efforts because of confirmed associations between adverse effects on wildlife and the presence of selenium in drainage water. Unlike other substances of primary concern, no practical treatment method for selenium removal was known to exist.

Treatment Processes

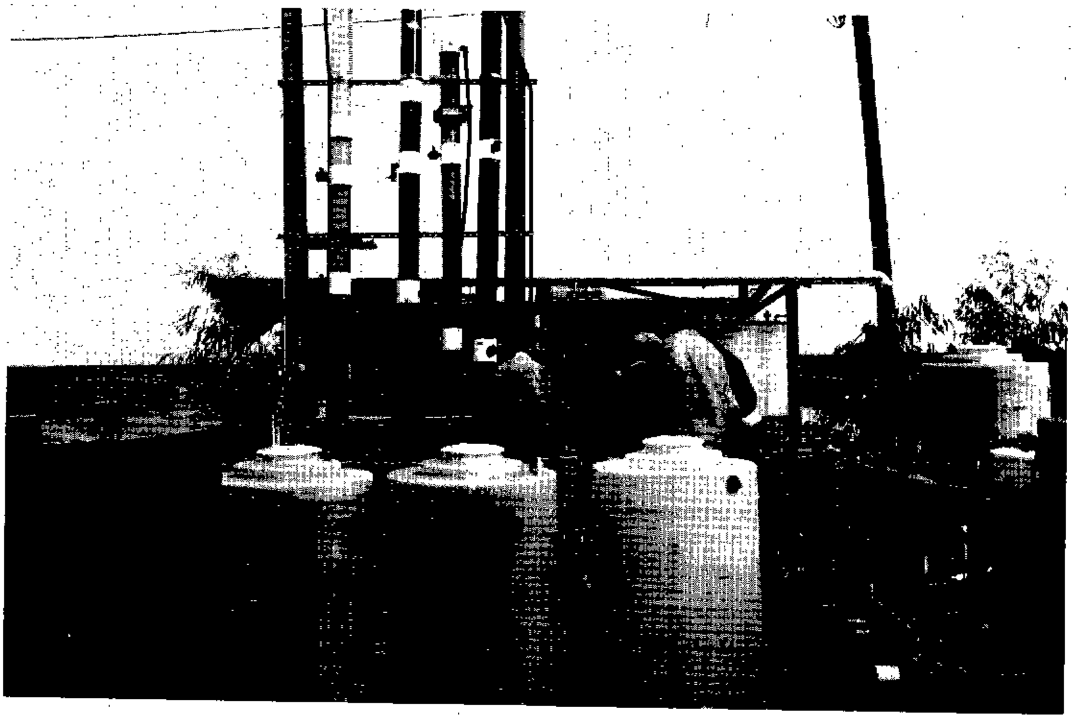
Problems at Kesterson Reservoir generated about 150 ideas and suggestions that were submitted to the Drainage Program. Many were oriented toward drainage water treatment and many were research proposals. The staff initially screened all the ideas and submitted about 30 of them to the Program's Treatment and Disposal Subcommittee for evaluation and final screening. The subcommittee further narrowed the choices, but because of funding limitations, only the most promising methods were pursued.

The Drainage Program investigated the 11 processes listed in Table 5 but did not fund all the developmental research. Others (for example, Westlands Water District, Panoche Drainage District, and the California Department of Water Resources) also funded research on treatment processes. Chapter 3 of the Drainage Program's *Preliminary Planning Alternatives* summarized the various treatment processes investigated. Technical reports on the various treatment processes have been prepared and a review and evaluation of each treatment process has been completed (Hanna, et al., 1990).

Anaerobic–Bacterial Process

This process was tested by EPOC AG in a small-scale pilot plant, using a biological reactor (including upflow fixed-film beds, fluidized beds, and sludge blanket reactors) and microfiltration. EPOC AG concluded in 1987 that the biological process is a practical and proven method for treatment of selenium-laden drainage.

The optimum treatment train was sludge blanket to fluidized bed to microfiltration. The process lowered selenium levels in the feedwater from 300 to 500 ppb down to 12 to 40 ppb, and thence to below 5.0 ppb with ion exchange "polishing." However, interpretation of the data generated by the EPOC AG pilot plant is complicated by the ever-changing nature of the plant's operation. It operated under field conditions, with wide changes in drainage water quality and diurnal and seasonal temperature variation, as well as in other significant parameters.



The anaerobic-bacterial process of removing selenium from drainage water was tested in this small plant near Mendota in 1986 and 1987.

Laboratory-scale research at the University of California, Davis, was conducted as followup to the work by EPOC AG, mainly to determine the mechanisms of selenium removal in the anaerobic-bacterial process (Schroeder, et al., 1989). It was determined from studies using sequencing batch reactors and fluidized bed reactors that selenate reduction occurred simultaneously with nitrate reduction. It was theorized that selenate reduction was primarily a detoxification mechanism, rather than a respiratory process. In respiration, nitrate would be used before selenate. The researchers postulated that the bacteria are detoxifying their environment of high concentrations of selenate, while simultaneously respiring on nitrate.

Facultative-Bacterial Process

This process was studied in the laboratory at the U.S. Bureau of Mines Research Center in Salt Lake City, Utah (Altringer, et al., 1987). Selenium was reduced from selenate to selenite, using facultative bacteria that can live with or without oxygen, and precipitated from solution in elemental form. This study also demonstrated that the mechanism of selenium removal is influenced by nutrient addition, oxygen supply, and temperature. Aerobic conditions encouraged bacterial growth, but selenate reduction was enhanced when the air supply was restricted.

Table 5. STATUS OF DRAINAGE-WATER TREATMENT PROCESSES TO REMOVE OR IMMOBILIZE SELENIUM

Process	Research	Development	Testing and Evaluation
Biological			
Anaerobic-bacterial			X
Facultative-bacterial	X		
Microalgal-bacterial		X	
Microbial volatilization in evaporation pond water	X		
Microbial volatilization from soils and sediments			X
Physical and Chemical			
Geochemical immobilization	X		
Iron filings			X
Ferrous hydroxide		X	
Ion exchange	X		
Reverse osmosis to remove salts and other contaminants			X
Generate electrical energy and heat for desalination with a cogeneration process			X

In many respects, the mechanism of selenium removal in this process appears similar to that occurring in the anaerobic-bacterial and microalgal-bacterial processes. It involves reducing selenate to selenite to elemental selenium, which accumulates in the biological sludge of the reactors. The same bacteria genus contained in EPOC AG's anoxic fixed-film reactor sludge was shown in this study to reduce selenate first and adapt well under high selenium concentrations. The study also demonstrated that optimal selenate reduction by facultative bacteria occurs under anoxic conditions.

Microalgal-Bacterial Process

This process was investigated by the University of California at Berkeley (Oswald, et al., 1990). The process is based on the principle that soluble selenate can be reduced by microorganisms to less-soluble selenite and elemental selenium in an anoxic sludge blanket reactor. While elemental selenium settles and accumulates in the reactor sludge, selenite suspended in the reactor effluent can be precipitated with ferric chloride and removed by a dissolved air flotation system.

The carbon source for the biological reactor is algae cultivated in high-rate algal ponds fed by drainage water. If drainage nitrate levels are above that which can be assimilated by pond algae, a denitrification reactor is added upstream from the selenate-reducing reactor.

The researchers believe that excess algae can be fermented to produce methane for power generation, carbon dioxide can be recycled for pH control in the algae ponds, and the digested sludge can be diverted to the biological reactors to supplement the algal feed. Although the field tests did not reach steady-state conditions, the process showed promise of greater than 95-percent removal of selenium.

Microbial Volatilization of Selenium in Evaporation Pond Water

This process was studied primarily as an in-situ means to maintain selenium levels in evaporation ponds below the hazardous waste criterion of 1.0 ppm. It was not intended to meet the more stringent criteria for wildlife protection.

Investigators in 1990 reported that compounds high in protein, such as casein, dramatically accelerate biological removal of selenium, but substantial amounts of the compounds are apparently required, probably creating eutrophic ponds (Frankenburger and Thompson-Eagle, 1989). Bacteria were identified as the predominant active selenium methylators in pond water. The researchers conclude that further studies are needed to determine whether protein-mediated methylation can be optimized through the addition of coenzymes, methyl donors, and aeration, as well as through the addition of specific microbial inoculants. They further conclude that it may be possible to design a pilot bioreactor to test selenium removal. This technique lags in developmental efforts.

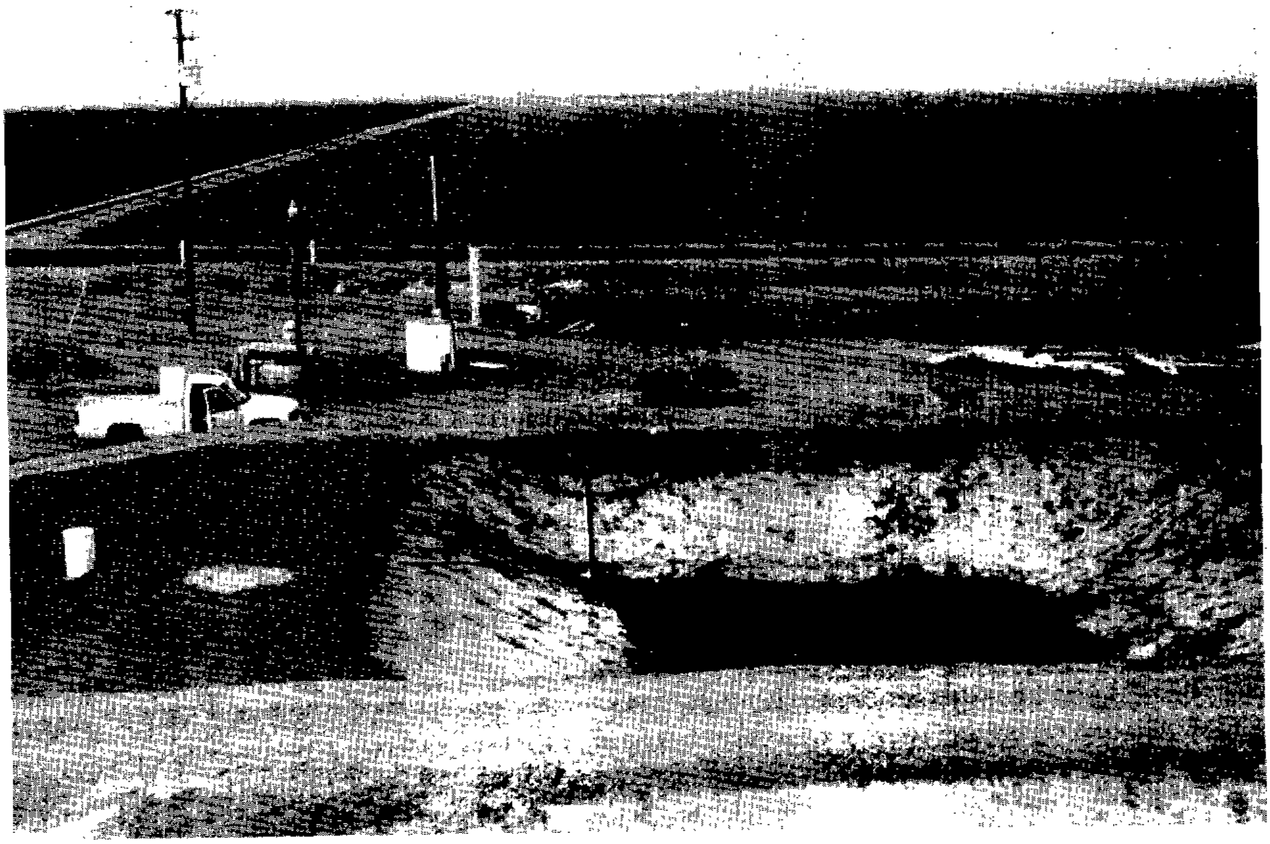
Microbial Volatilization of Selenium from Soils and Sediments

This process is being investigated by researchers from the University of California at Riverside to determine whether biomethylation of selenium could be accelerated and used as a bioremediation technique to remove selenium from Kesterson Reservoir and the San Luis Drain (Frankenburger and Karlson, 1989). Indigenous soil fungi are the primary organisms that volatilize the selenium, and dimethylselenide is the primary gaseous end product. The process was field-tested, following treatment methods in which different additives were used. This work was done at Kesterson Reservoir, on San Luis Drain sediments, and at a Peck Ranch evaporation pond. All treatments included moisture application and rototilling.

At Kesterson Pond 4, where selenium concentration in the upper 6 inches of soil averaged about 39 milligrams per kilogram, treatment using citrus peel + ammonium nitrate + zinc sulfate and treatment using casein were most effective. The average emission rate with the citrus peel treatment was about 40 times greater than it was for background level. It was estimated that the treatment would require about seven years to achieve the cleanup goal of 4 mg/kg from the initial concentration of 39 mg/kg. The selenium volatilization rate is highly temperature-dependent, with the highest rates occurring in the late spring and summer months.

Geochemical Immobilization

A physical/chemical attenuation process to transform and immobilize selenium in place was investigated by UC Riverside researchers (Neal and Sposito, 1988). The study was conducted to identify the pertinent variables in an irrigated soils system designed to implement management techniques that would control the eventual fate of selenium by immobilizing it in the soil profile. The researchers concluded that the chemical form in which selenium exists in the aqueous phase governs the applicability of this process. If, as in the soils of the western San Joaquin Valley, selenate predominates, farm level management practices to achieve physical/chemical attenuation would have little success in immobilizing selenium.



Panoche Water District is testing the removal of selenium by passing drainage water through a bed of iron filings in the bottom of this basin.

Iron Filings

In 1985, Harza Engineering Company tested its patented heavy metals adsorption process for removing selenium from drainage water at Panoche Drainage District. In this process, heavy and toxic metals are adsorbed onto iron filings and removed from solution as drainage water flows through a bed of "activated" iron filings. Before the beds are exhausted, the iron filings are replaced, activated, and returned online. The spent material can be disposed of at landfills or recycled to the metal-working industry.

A problem arose in initial field testing. The filings solidified and clogged the bed. A study was conducted at the University of Wisconsin, Madison, to determine the mechanism by which selenium is removed and the selenium specie formed to effect removal (Harza, 1989). It was concluded that selenium is removed by chemical adsorption on iron oxyhydroxide surfaces at an orange-brown layer of iron filings, where drainage water enters the column. Before the oxyhydroxide layer forms, selenium can be removed throughout the iron-filing bed by physical adsorption. There is still uncertainty regarding the exact mechanism whereby selenium is removed in the Harza process.

The study did not conclusively define the cause of the bed-clogging problem. The formation of magnetite (Fe_3O_4), a ferromagnetic solid that restricts flow, was suggested as a possible cause. Other possibilities, such as calcite precipitation, were also suggested, but bed-hardening also occurred in columns with selenate-spiked distilled water.

Pilot tests are presently being conducted in treatment ponds at Panoche Drainage District. Information from these tests should help to better evaluate the effectiveness and cost of this process.

Ferrous Hydroxide

Studies of this process were conducted by staff of the U.S. Bureau of Reclamation's Denver Office (Rowley, et al., 1990). The process is based on a reaction in which ferrous hydroxide reduces selenate to elemental selenium. The reaction rate depends on pH, for which the optimum range is 8 to 10. Temperature affects the rate of selenate removal by about doubling the rate for each 10° C increase. Most of the tests were conducted at 20° C, the approximate average temperature of drainage water.

The reaction time for selenate removal is inversely proportional to the ferrous hydroxide concentration, which was commonly used in the range of 2.5 to 20 millimoles per liter. The reaction times were very short (99-percent selenate removal in less than one minute) when deionized water was used for testing, but substantially longer times were required when drainage water was used. Field tests near Mendota resulted in 90-percent selenate removal after four hours.

It was concluded that high concentrations of bicarbonate would decrease the reaction rate by half, while high concentrations of nitrate would reduce the reaction rate by a factor of 5. If high concentrations of both ions were present, the initial rate of reaction would be reduced by a factor of 17. Although oxygen does not appear to affect the rate of selenate removal, it oxidizes about 1.6 millimoles per liter of ferrous hydroxide if the water is saturated at 20° C.

Ion Exchange

Use of selenium-selected resins to remove selenium was investigated in laboratory tests on drainage-water samples (Boyle, 1988). Two strong anion-base resins, both similar to commercial resins, showed selectivity for the selenate ion over the sulfate ion. The investigators concluded that this indicated ion exchange is a promising method. However, studies have not been conducted to demonstrate field-scale reliability and costs.

Reverse Osmosis to Remove Salts and Contaminants

This is a versatile, proven treatment process capable of removing salts, as well as trace-element contaminants, but it is also much more costly than the other treatment processes. The California Department of Water Resources operated a drainage-water desalting demonstration plant at Los Banos from the fall of 1983 to August 1986. DWR concluded that additional work is required on the pretreatment system to establish the feasibility of a drainage water desalting facility. DWR has issued a report on the pretreatment systems tested (DWR, 1986), and reports on other components of the project (ion exchange and reverse osmosis) are being completed.

Cogeneration

This process uses waste heat from the thermal generation of energy to evaporate drainage water. However, from review of a cogeneration study completed in 1989 (RMI, 1989), the Drainage Program concluded that cogeneration using natural gas fuel is not promising for evaporation of unconcentrated drainage water because of the high cost and the relatively small amount of drainage water treated (about 7,500 acre-feet annually in conjunction with a 100-megawatt powerplant).

Westlands Water District, with Drainage Program participation, conducted a preliminary study of burning salt-tolerant agroforest biomass to evaporate drainage water concentrated by agroforestry crops (RMI, 1990). RMI concluded that wood fuel cannot be economically substituted for natural gas to fuel a cogeneration component of a drainage water evaporation plant.

Future of Treatment Processes

The implementation of any drainage water treatment process is burdened largely by three major items: (1) The need to keep costs low and affordable for agricultural application, (2) the stringent performance criteria imposed by the need to reduce selenium to extremely low concentrations (less than 5 ppb) in receiving water, and (3) the early developmental status of technology for selenium removal from drainage water. Because selenium-removal technology, unlike reverse-osmosis desalting, has not progressed to large-scale application, it is premature to recommend a specific treatment process at this time. However, selenium removal research indicates that treatment may be a viable drainage management strategy under certain conditions and, therefore, further treatment research is justified.

Because the Drainage Program wanted to encourage the search for an economical way to remove selenium from drainage water, its Interagency Technical Advisory Committee's Treatment and Disposal Subcommittee was asked for advice on which process to pursue. The subcommittee recommended support of a 30,000-gallon-per-day demonstration plant using the anaerobic-bacterial process field-tested by EPOC AG. The Department of Water

Resources intends to fund the demonstration plant in 1990, with support from the U.S. Bureau of Reclamation.

In the EPOC AG field-pilot tests, selenium in drainage water at a concentration of 300 to 550 ppb was lowered to about 10 to 40 ppb after microfiltration and to less than 10 ppb after polishing in boron selective ion-exchange resins. EPOC AG has reported estimated treatment costs for a 1-million-gallon-per-day prototype plant of about $76 per acre-foot to construct (capital at 4 percent, with 20-year plant life) and $148 per acre-foot to operate. Total product cost would be about $224 per acre-foot. It was also estimated that, for a 10-mgd plant, the total unit treatment cost would decline to about $145 to $175 per acre-foot, depending on the availability and cost of a carbon source. These estimates did not include waste-stream disposal costs.

A study sponsored by the Drainage Program reviewed and evaluated each treatment process investigated, and, when cost estimates were available, adjusted them on a common basis (Hanna, et al., 1990). Revisions of EPOC AG's cost estimates were based on increases in the interest rate from 4 percent to 9⅜ percent, electricity rates from $0.045 to $0.08 per kilowatt-hour, labor costs from $28,470 to $40,000 per person per year, and capital costs by 35 percent. Added to these were replacement costs and 27 percent for overhead and profit. Those changes raised the estimated total product cost from $224 to $456 per acre-foot for a 1-mgd plant and from $175 to $301 for a 10-mgd plant. Neither estimate includes costs of polishing to lower selenium levels to less than 10 ppb, or of waste-stream disposal.

Reuse

If drainage water could be economically reused, it would be a resource, not a waste disposal problem. The Drainage Program funded investigations of the reuse of drainage water for irrigation of salt-tolerant trees and halophytes. It also reviewed the results of reuse investigations conducted by others. These mainly concerned the use of drainage water in powerplant cooling, temperature-gradient solar ponds, aquaculture, salt and mineral recovery and marketing, and agriculture.

There are no current plans for siting major thermal powerplants in the valley and hence no significant demands for drainage water for cooling. Treatment costs would be substantial to produce drainage water acceptable for powerplant cooling. Possibilities exist, though, that energy-producing solar ponds could be used in drainage water management because of the increasing demand for, and cost of, electrical energy and because of growing concern for air quality in California. Both the Bureau of Reclamation and the Department of Water Resources are pursuing further solar pond investigations.

The potential for both salt and mineral recovery and aquacultural reuse rests largely with the marketability of the products — primarily sodium sulfate, in the case of salt recovery, and the products grown in drainage water, in the case of aquaculture. Such markets do not appear promising at present because sources are available elsewhere, but these are subject to change in the future.

Reuse of drainage water by irrigating salt-tolerant crops or by blending with normal irrigation supplies are the only reuse options that appear promising at this time.

AGRICULTURAL ECONOMY

Agriculture is the mainstay of the economy of the westside San Joaquin Valley. Knowledge of the agricultural economy and the way in which it relates to the region, the State, and the nation are important to understanding and planning for management of the drainage problem. The information that follows is from the Census of Agriculture reports (1978, 1982, 1987), Census of Manufacture reports (1978, 1982, 1983, and 1985), and data from the California Department of Food and Agriculture and a commercial agricultural lending agency, as presented in a report sponsored by the Drainage Program (Archibald, 1990). Additional information is available in the full report.

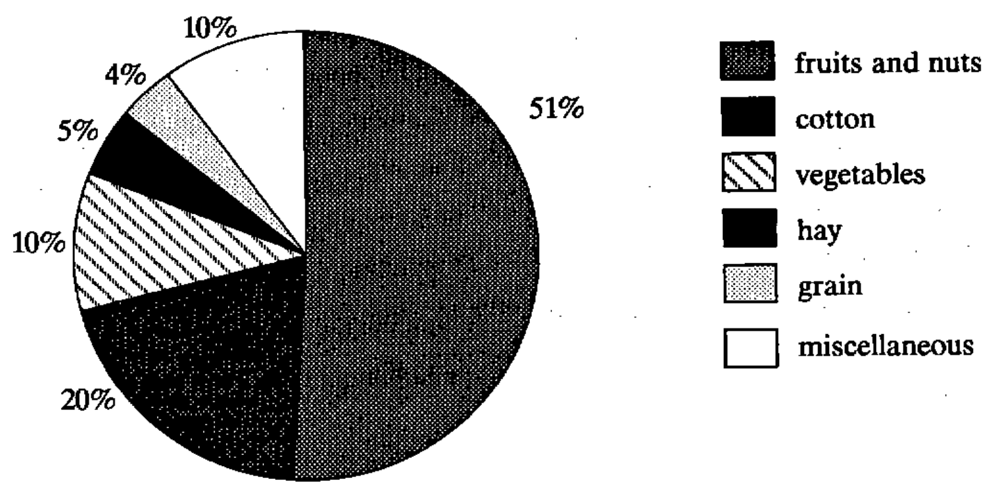
The Contribution of Agriculture

California leads the nation in the market value of agricultural production. In 1987, California's total value of agricultural output was $13.92 billion; this represented 10.2 percent of the total $136 billion U.S. agricultural production. Of the California total, $9.27 billion was contributed by crops and $4.65 billion by livestock, poultry, and related products.

The San Joaquin Valley is California's largest single agricultural area, contributing $6.82 billion (49 percent) of the State's total agricultural output. Crops accounted for $4.45 billion (65 percent), and livestock and livestock products contributed $2.37 billion (35 percent). Figure 13 provides a breakdown of the total crop production value in the San Joaquin Valley.

Of the total value of crop production in the U.S., 50.9 percent was derived from irrigated land and 49.1 percent from nonirrigated land. In contrast, only 19.9 percent of the value of livestock and livestock products was derived from irrigated land, while 80.1 percent was

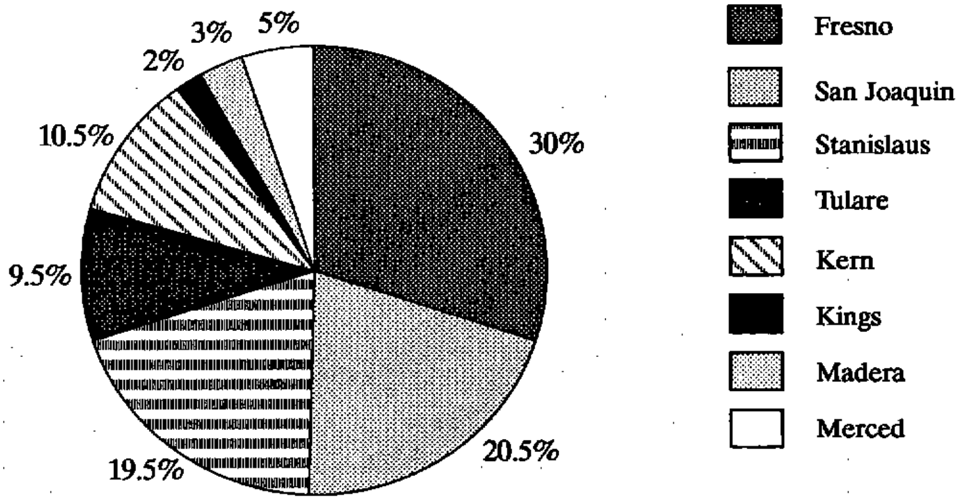
Figure 13. SAN JOAQUIN VALLEY TOTAL CROP PRODUCTION VALUE (Value = $4.45 billion in 1987)



contributed by nonirrigated land. Irrigated land in California accounted for about 45 percent of total U.S. crop production on irrigated land, and the San Joaquin Valley alone contributed about 21 percent of the U.S. total.

The importance of agriculture to the economy of California can be estimated by examining employment statistics. Statewide in 1987, agriculturally induced employment accounted for at least 17.3 percent of employment and 18.5 percent of total payroll. Within the San Joaquin Valley, these categories were 48.6 and 54.2 percent, respectively. Figure 14 shows agriculturally induced employment in the San Joaquin Valley.

Figure 14. AGRICULTURALLY INDUCED EMPLOYMENT IN THE SAN JOAQUIN VALLEY BY COUNTY, 1987



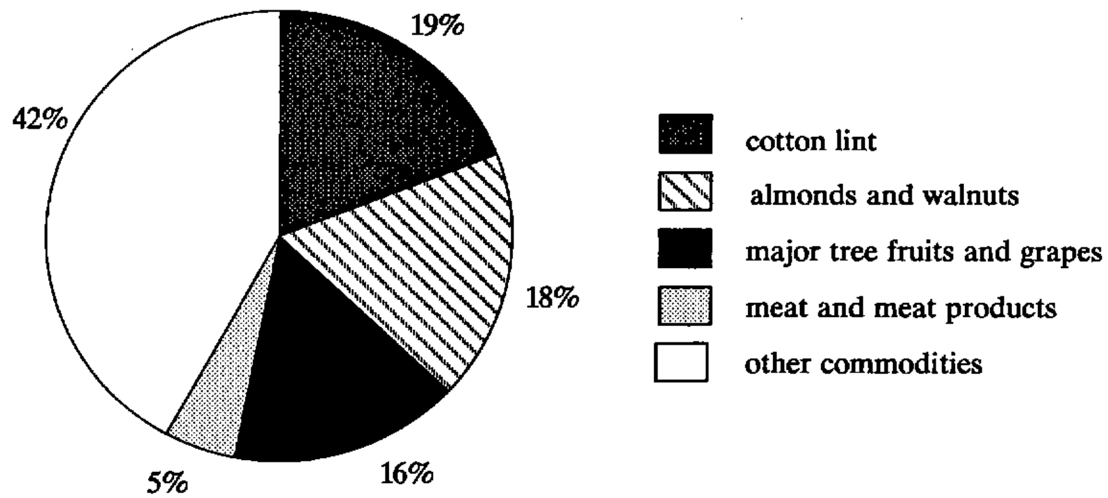
In 1987, agriculturally induced employment in each valley county was even more striking, representing more than 50 percent of employment in Kings, Madera, Merced, and Stanislaus counties and about 50 percent in Fresno, San Joaquin, and Tulare counties. In Kern County, agriculture accounted for only 20 percent of employment, reflecting the development and growing importance of other industries, such as petroleum.

Exports

California also leads the nation in agricultural export value. The State's export value declined during the 1980s, as did U.S. export value, but the State's value recovered significantly by 1987. The leading single export commodity from California is cotton lint. Figure 15 shows a breakdown of the value of California commodity exports. In 1987, 62 percent of California's cotton output was exported. This accounted for nearly half the value of U.S. cotton exports. About 60 percent of the State's almond crop and 45 percent of the walnut crop were exported. This was the entire amount of U.S. exports of these two crops.

Given these levels of exports, an estimated 1.76 million acres of California cropland were dedicated to producing for export markets in 1987. Cotton dominates exports in terms of land use. In 1987, production from 710,000 acres of cotton was required to meet California's

Figure 15. SHARE OF CALIFORNIA COMMODITY EXPORTS, BY VALUE, 1987



export market. Of that area, 682,000 acres were in the San Joaquin Valley, and 450,000 of those acres are on the valley's western side. The rise in incomes in countries importing agricultural products from California favors growth in higher value export crops, such as fruits, nuts, and beef. For the 1990s, based on expectations of income and population growth in importing countries, the U.S. Department of Agriculture projects a 3-percent annual growth rate for agricultural exports, led by growth in high-value products. Food grain exports are not expected to grow as fast as feed grain exports, because importing countries are increasing their domestic meat production and must import feed grains.

Land Use

Total California farmland in 1987 was 30.6 million acres, with about one-third (10.5 million acres) in the San Joaquin Valley. Farmland on the western side of the valley accounts for one-third (3.4 million acres) of the valley total. About 7.5 million acres of cropland are irrigated, with irrigated pasture accounting for only 5 percent of the total. Over half (57 percent) of the State's irrigated cropland is in the valley, and 40 percent of this is on the western side. Together, the Westlands, Tulare, and Kern Subareas account for more than 75 percent of westside irrigated cropland.

California farmland as a whole declined 2.3 percent from 1982 to 1987, a drop that was consistent with the national pattern, which declined 2.26 percent in the same period. For the valley, the decline was 3.0 percent; on the western side, it was 11 percent.

A partial explanation for the decline of irrigated westside cropland is the acreage enrolled in the Federal Commodity Acreage Reduction Program and the Conservation Reserve Program. Idled cropland in the valley increased 125 percent from 1982 to 1987, or 13.4 percent of total irrigated cropland in 1987. Land under the Acreage Reduction Program increased 256 percent from 1982 to 1987, to a total of 7.1 percent. Land set aside under the Conservation

Reserve Program for the valley as a whole was less then 1 percent of irrigated land. Drought conditions in 1987 also help explain the reduction in irrigated acreage.

Forty-three percent of irrigated cropland on the western side of the San Joaquin Valley was in cotton in 1987. In the five subareas, the share of cropland in cotton ranged from 2.1 percent in the Northern Subarea to 52.2 percent in the Westlands Subarea (Figure 16). The cotton shares for the Kern, Tulare, and Grasslands subareas are 51.0, 49.5, and 34.6 percent, respectively. Other field crops, including feed grains, hay, wheat, sugar beets, dry beans, oilseeds, and rice, accounted for 34.3 percent of the valley's cropland and 38.4 percent of the westside cropland in 1987. The shares of cropland in these field crops ranged from 28.7 percent in the Westlands Subarea to 51.9 percent in the Northern Subarea. Most dry beans have been grown in the Northern Subarea; most sugar beets, in the Northern and Grasslands subareas; and most oilseeds, in the Tulare Subarea. Conversely, hay has been grown throughout the west side, but minimally in the Westlands Subarea. Cotton is minimal in the Northern Subarea, as is wheat in the Grasslands Subarea.

In 1987, fruit and nut acreage represented 8.3 percent of cropland on the western side and 33.4 percent in the San Joaquin Valley as a whole (Figure 16). Together, almonds, walnuts, and apricots accounted for 92 and 86 percent of tree and vineyard cropland in the Northern and Grasslands subareas, respectively.

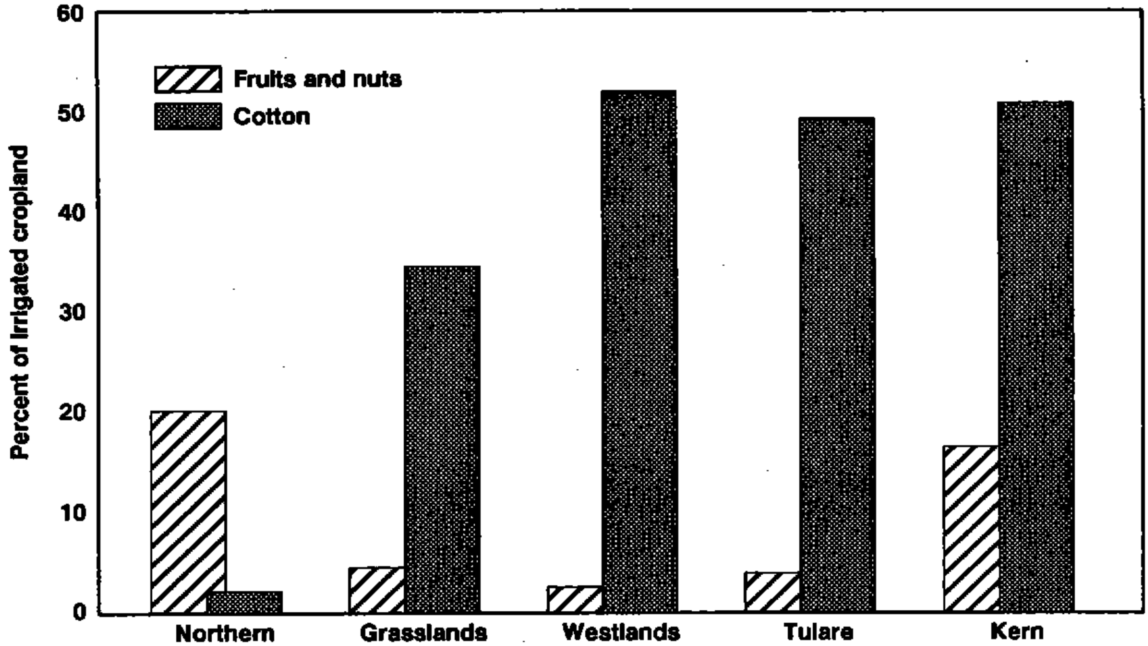
In 1987, vegetables accounted for 10.3 percent of cropland on the western side, up from 7.7 percent in 1982 and 7.3 percent in 1978. This represented an increase of 17,000 acres during the 10-year period. The share of cropland in vegetables ranged among the subareas from a high of 25.8 percent in the Northern Subarea to a low of 2.8 percent in the Tulare Subarea. Westlands Water District, which makes up most of the Westlands Subarea, had the greatest vegetable acreage, with140,868 acres (Westlands Water District, 1988). Tomatoes, cantaloupes, lettuce, romaine, and dry onions occupied about 62 percent of land planted to vegetables in the valley. Tomatoes were the dominant crop, with 36 percent of the vegetable acreage.

Production Expenses

The western side of the San Joaquin Valley accounted for 29 percent of total valley agricultural production expenses in 1987. Given that the westside share of irrigated cropland is 40 percent, this indicates lower per-acre expenses for the western side than for the remainder of the valley. This could reflect a combination of a greater ratio of field and row crops to trees and vines on the western side and some economies of scale associated with large operations. Labor expenditures exceeded 20 percent of the total, followed by chemicals and machinery (including equipment), each at 10 percent, and energy at 6 percent. The shares of expenditures for labor, interest, and property taxes are lower than for the rest of the valley. Westside growers, however, dedicate a larger fraction of their production expenses to machinery, energy, chemicals, and irrigation water. In the subareas, cash rents per acre appear to decline as a proportion of total expenditures from north to south. The proportion of expenses in the form of interest payments was greater in the Northern Subarea, reflecting higher land values and per-acre investments in orchards. Energy expenditures in the Tulare and Kern Subareas were greater in proportion to other expenses than in other areas, reflecting the greater dependence on pumped ground water as an irrigation supply.

Westside land values have followed the national pattern, increasing from 1970 to the early 1980s and then declining, with some recent evidence of recovery. Westside land prices are about five times the national average and are highest in the Northern Subarea, where orchards are prevalent.

Figure 16. IRRIGATED CROPLAND IN COTTON, FRUITS, AND NUTS, BY SUBAREA – 1987



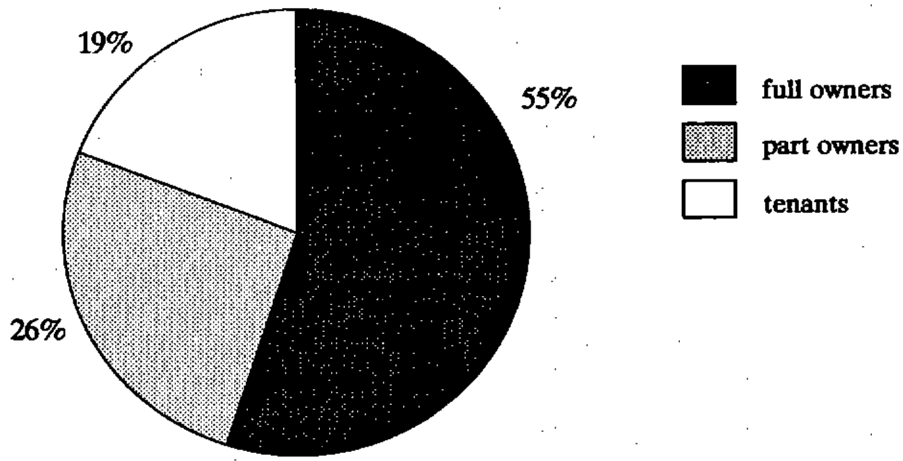
Farm Structure

Farms are fewer but substantially larger on the western side than in the rest of the valley. Average farm size in the principal study area was about 500 acres in 1987, while the average for the rest of the valley was about 100 acres. Farms in the Westlands Subarea averaged 1,100 acres in 1987; in the Tulare and Kern subareas, 500+ acres; in the Grasslands Subarea, 400+ acres; and in the Northern Subarea, 200 acres.

Farm tenure types fall into three classifications: (1) Full owners, who operate only the land they own; (2) part owners, who operate farmland they own, as well as land they rent; and (3) tenants, who operate only land they rent (Figure 17). Full ownership as a percentage of all forms of land tenure on the western side exceeded 50 percent in all subareas, except in Westlands, where it was 44 percent.

Farm operations are also divided into three basic types of management structures: corporations, partnerships, and individual or family owners. Corporations are further divided into three groups: family-held; other-than-family-held; and others, including cooperatives. In 1987, individual owners and family corporations together accounted for 76.3 percent of the farms on the westside San Joaquin Valley. In the Northern and Grasslands Subareas, corporations accounted for less than 1 percent of farms and less than 2 percent in

Figure 17. PERCENT OF FARMS BY TENURE OF OPERATOR, WESTSIDE SAN JOAQUIN VALLEY, 1987



each of the other subareas. All subareas had more than 70 percent of farms under individual ownership or in family corporations.

Less than 0.5 percent of farmland in the Northern and Grasslands Subareas was owned by corporations. During the 10-year period, 1978-1987, the portion of land owned by corporations in the Westlands and Kern Subareas increased from 6 percent to 8 percent and from 7 percent to 8 percent, respectively. In the Tulare Subarea, the portion increased from 7 percent to 16 percent. During the same period, land owned by partnerships in the Grasslands and Kern Subareas increased from 32 percent to 40 percent and from 35 percent to 40 percent, respectively. In the Westlands Subarea, the portion increased from 28 percent to 34 percent, while in the Tulare Subarea it increased from 25 percent to 35 percent. Only the Northern Subarea reported a decrease in land owned by partnerships during this period — from 38 percent to 36 percent.

Federal Agricultural Programs

Commodity Credit Corporation (CCC) payments to farm operators include loans for corn, wheat, sorghum, barley, oats, cotton, rye, rice, and honey. Government payments include deficiency payments, paid diversions, soil conservation reserve payments, payments from the Dairy Termination Program, other conservation programs, and other Federal farm programs under which payments are made directly to the farm operator. In 1987, CCC and other government payments to U.S. farms totaled $17.9 billion; $570 million was for loans and the remainder for payments. California received $69.1 million in CCC loans and $238 million for government payments. Total CCC payments for the San Joaquin Valley were $17 million, amounting to 28 percent of California payments. The valley received $126 million in government payments, or 53 percent of the State total. CCC loans to the western side for all program crops totaled $11.7 million.

Cotton was the most important source of CCC payments (83.6 percent) on the western side. In the Kern Subarea, 97 percent of CCC loan payments was for cotton, and the Grasslands and Westlands subareas received 75 and 84 percent, respectively, for cotton. The Northern Subarea received almost 40 percent of its CCC payments for corn, almost 50 percent for rice, and the balance for wheat. Feed-grain payments were negligible in the other subareas.

While more than 25 percent of U.S. cotton farms participate in the CCC loan program, only 10 percent do so on the western side of the valley and in the State. In 1987, the Grasslands Subarea accounted for 13.8 percent of the westside acreage in program crops, but farmers in the subarea received 23 percent of the CCC loans. The Westlands Subarea had 27.2 percent of the acreage in program crops and received 33.1 percent of the payments. The Kern Subarea had about 25 percent of the acreage and CCC receipts. The Tulare Subarea had 32.8 percent of the acreage and 18.3 percent of loan payments.

In 1987, westside farms received 0.6 percent of total U.S. payments and CCC loans to all farms, 2.5 percent of payments and loans to farms with any land irrigated, and 7.3 percent of payments and loans to irrigated farms. The San Joaquin Valley as a whole contributed 21.3 percent of the value of U.S. agricultural output from irrigated farms and received 10.5 percent of government payments to irrigated farms.

FISH AND WILDLIFE RESOURCES

[Data, references, and analyses supporting the information included in this section can be found in the Drainage Program's 1989 report, Preliminary Planning Alternatives.*]*

Habitat Losses and Population Declines

Long ago, seasonal flooding of large areas of the San Joaquin Valley floor created a patchwork of aquatic, wetland, riparian forest, and valley oak savannah habitats. Surrounding these overflow lands were large areas of California prairie and San Joaquin saltbush. In the southern part of the valley, Tulare Lake and four smaller lakes were interconnected by a vast network of sloughs, riparian forests, and wetlands. On the average, during the past few thousand years, all five lakes in the Tulare Basin covered a total of about 516,000 to 625,000 acres, or about 800 to 1,000 square miles.

The diversity of habitats in the valley supported large populations of resident and migratory species of fish and wildlife. Before the region was settled, the year-round native plant and animal life in the Tulare Basin was so abundant that it supported the densest population of native Americans on the North American continent that was not engaged in agriculture. During the late 1800s, enormous numbers of waterfowl and fur-bearing mammals were commercially harvested throughout the San Joaquin Valley, and Tulare Lake supported a small commercial fishery for western pond turtles and native minnows.

Widespread development of agricultural lands, draining of the once-extensive lakes, drastically reduced instream flows, and declining water quality have taken a substantial toll on the native aquatic, wetland, riparian, and terrestrial habitats of the San Joaquin Valley. The present acreage of natural freshwater lakes on the valley floor is less than 1 percent of

Migrating ducks rising from a pond in wetlands of the Grasslands Subarea on the Pacific Flyway.

the historic extent. Current acreages of wetland and riparian habitats are less than 15 percent and about 7 percent, respectively, of their historic extent. San Joaquin saltbush habitat now occupies less than 7 percent of its historic acreage. Such drastic reductions of these habitats have caused the decline of many species of plants and animals endemic to the valley. Several species that once occurred in the valley no longer exist there or have become extinct, and 29 others are listed as endangered by the Federal or State governments.

Water Supplies and Needs

About 200,000 acres of public and private land in the San Joaquin Valley are managed primarily for the benefit of fish and wildlife. These areas need over 400,000 acre-feet per year of fresh water to satisfy optimum management needs. Reliable firm supplies of fresh water for these areas currently total about 30 percent of needs.

At present, about 4.7 million acres of irrigated agricultural land in the San Joaquin Valley receive about 17.6 million acre-feet per year of irrigation water. Until recently, surface and subsurface agricultural drainage from some of these lands, commingled with other surface water, provided over 50 percent of the water used by fish and wildlife areas, and these waters still provide instream flows for fisheries and other beneficial uses.

Several major dam, reservoir, and canal systems have been constructed and are operated in the Central Valley to serve agricultural and urban water needs. These projects have created many severe problems for fisheries in the San Joaquin and other river systems. Although specific instream flow needs for many streams and associated fisheries in the valley have not yet been determined, it is apparent that instream flows in the mainstem San Joaquin (above its confluence with the Merced River) and in the major tributaries are currently inadequate to sustain migration of salmon. Further study is needed to determine instream flow needs of San Joaquin River fisheries. Additional planning, analysis, and field testing of methods to provide adequate and firm supplies of clean, fresh water for valley fish and wildlife are also warranted.

Toxicity of Drainage-Water Contaminants

Analyses of subsurface agricultural drainage water have revealed high salinity and elevated concentrations of toxic or potentially toxic elements (including arsenic, boron, cadmium, chromium, copper, lithium, manganese, molybdenum, nickel, selenium, strontium, uranium, vanadium, and zinc). Recent laboratory and field toxicity research reveals that fish and wildlife are more sensitive to the toxic properties of several of these chemical elements than previously believed. This is illustrated by the following examples for selenium, boron, and salts.

The U.S. Environmental Protection Agency's ambient freshwater aquatic life water-quality criterion for selenium was recently reduced from 35 to 5 ppb. The State Water Resources Control Board and the Central Valley Regional Water Quality Control Board have recommended that water used for wetlands management in the Grasslands Subarea contain average selenium concentrations of 2 ppb or less. Furthermore, University of California scientists have identified 1.0 to 1.5 ppb waterborne selenium as the range that causes no adverse effects. Selenium concentrations in North Mud and Salt Sloughs in the Grasslands Subarea average 6.0 ppb. Selenium concentrations in the 7,000 acres of evaporation ponds average 49 ppb, based on acreage-weighted means, and range above 1,000 ppb.

Boron, which was previously thought to be nontoxic to wildlife, has been shown to have adverse effects upon wildlife at concentrations of 900 ppm (dry weight) in the diet. Waterfowl food-chain organisms collected from Kesterson Reservoir and several other evaporation ponds in the valley have been found to contain concentrations of boron that approach or exceed this toxic threshold.

Highly saline water, free from elevated concentrations of trace elements, can also pose a health threat to wildlife. For example, freshwater ducklings are very sensitive to salty water. Toxicity tests with mallard ducklings have shown that molt was slowed when they were provided a single source of drinking water containing

Embryo of a black-necked stilt deformed by selenium poisoning.

3,000 ppm total dissolved solids, and growth was reduced when their sole source of drinking water was 7,720 µS/cm electrical conductivity. In addition to containing elevated concentrations of various trace elements, evaporation ponds in the San Joaquin Valley, heavily used by ducks and other aquatic birds for nesting and rearing of young, are also very saline — up to 388,000 ppm TDS — and average 31,850 ppm TDS, about equal to seawater. The combination of saline ponds and the extremely limited acreage of freshwater wetlands in the southern San Joaquin Valley during the spring breeding season potentially increases this toxic threat to aquatic birds.

Finally, the toxicity to fish and wildlife of various salts and trace elements carried in drainage water depends upon, among other variables, the species, life stage, health, and diet of the target organism; the chemical form of the contaminant; the bioavailability of the contaminant (which for waterborne concentrations can be affected by other chemical characteristics of the water); and the interactions (additive, synergistic, and antagonistic) of multiple contaminants. Very little information is available regarding many of these complex issues, and additional research is warranted.

Contamination and Biological Effects

Elevated concentrations of drainage-water contaminants have been discovered in water, sediments, food-chain organisms, and major vertebrates in a number of San Joaquin Valley areas outside Kesterson Reservoir and the San Luis Drain. These areas include rivers, streams, and ponds; riparian zones and wetlands; and upland sites. All these areas (both natural and manmade) provide fish and/or wildlife habitat. In several of them, elevated contaminant concentrations exceed documented toxicity thresholds, and studies have documented adverse biological effects that are believed to be contaminant-related.

In the San Joaquin Basin, the same drainage water that previously was used to flood wetlands in the Grasslands area is now being discharged into various canals and natural channels for conveyance to the San Joaquin River. In the Tulare Basin, the number and size of evaporation ponds receiving drainage water have continued to increase.

Evaporative concentration is dramatically increasing the waterborne concentrations of drainage-water contaminants such as boron and molybdenum in these ponds. In addition, through bioconcentration and possibly biomagnification, aquatic plants and animals can accumulate tissue concentrations of some drainage contaminants 100 to 10,000 times greater than those in the water. Statistically significant adverse biological effects (including impaired egg hatchability, elevated frequencies of embryo deformities, and reproductive failure) have been documented at seven of the valley's evaporation pond systems (about 58 percent of the ponds studied, which represent about 60 percent of the total acreage of ponds in the valley). Not all evaporation ponds have been studied, and efforts to date have focused upon breeding birds. Additional research is needed to determine whether adverse biological effects are occurring at other ponds and what effects, if any, operation of the ponds is having on wintering waterfowl and shorebirds, endangered species, and public health. Additional field research is also needed to field-test techniques for decontaminating and restoring drainage-water-contaminated fish and wildlife habitats and significantly reducing or eliminating the hazards posed to wildlife by evaporation ponds.

A test plot of eucalyptus trees (background) and atriplex (fore- and midground) being irrigated with drainage water. Plant transpiration reduces the water volume and concentrates the salts in the remaining drainage.

Agroforestry Plantations

Agroforestry plantations are being established in the study area in an attempt to reduce the magnitude of agricultural drainage-related problems. The trees (primarily eucalyptus) and halophytes (such as atriplex) are used to: (1) Lower the ground-water table and (2) reduce the volume of drainage water by increasing evapotranspiration. Recent studies have shown that the plantations provide habitat for several species of wildlife, including mourning doves, ring-necked pheasants, blacktailed jackrabbits, desert cottontails, a wide variety of songbirds, and possibly some large mammals such as foxes and coyotes. The plantations may benefit both farmers and wildlife. However, where they are irrigated with concentrated drainage water, more research is needed to determine whether these sites pose a contaminant hazard to wildlife. Appropriate management practices that will either increase wildlife values or reduce or eliminate contaminant hazards must be identified.

PUBLIC HEALTH

Public health concerns associated with drainage water were investigated during this study (Klasing and Pilch, 1988; Klasing, et al., 1990). Table 6 summarizes the concerns with drinking water, food crops, fish and game, and occupational exposures.

Safety of Food Crops

To date, selenium concentrations have been measured in about 125 food-crop samples grown in the western San Joaquin Valley, as well as in the milk and liver of some cows raised in the area. Overall, selenium concentrations in crops from the study area were similar to typical

U.S. selenium concentrations reported for those samples. Of the food samples analyzed, even daily consumption of the crops with the highest selenium levels found in the western part of the valley would not approach the quantity necessary for selenium toxicity. At most, they would provide part of the nutritional requirement for selenium in the human diet. The selenium content of cow's milk and liver obtained from the study area were similar to that for crops; however, the extent to which these cattle may have been exposed to elevated concentrations of selenium is unknown.

Certain crops in isolated areas may possibly contain higher concentrations of selenium than have been previously measured. If this is the case, persons who place heavy reliance on those foodstuffs to meet their dietary needs (such as may occur with subsistence gardening) would increase the risk of selenium toxicity. However, this has not been reported to have occurred in the westside San Joaquin Valley. Most consumers eat a variety of foodstuffs from many geographic areas. Persons whose consumption patterns are limited either to a small number of foodstuffs or to a very small geographic region may increase their risk of both deficiencies and excesses of trace elements in their diet.

The risk to public health from potentially elevated concentrations of other agricultural drainage-water contaminants in foodstuffs is not known at this time. Currently, several other elements (arsenic, boron, and molybdenum) that have been found to be elevated in some agricultural drainage water are being analyzed in local food crops.

Safety of Consuming Fish and Game

Because selenium can be concentrated by some aquatic plants and invertebrates to levels far higher than those found in the water in which they grow, selenium from agricultural drainage water has become toxic to some aquatic birds that feed in drainage-contaminated aquatic environments. Fish and aquatic birds may in turn accumulate relatively high concentrations of selenium in their tissues, becoming a potential health risk to humans who consume them. A survey of these species at specific locations within the western San Joaquin Valley has shown that unrestricted consumption of contaminated fish or game over an extended period could cause recognizable signs of selenium toxicity. To date, however, selenium toxicity in humans has not been reported to public health officials or confirmed as a result of such consumption.

Studies of other agricultural drainage-water contaminants in the tissues of fish and wildlife have not shown risks that exceed those from exposure to selenium. Therefore, procedures currently recommended to reduce selenium exposure from contaminated fish and wildlife (for example, health advisories to limit consumption of such game) can be expected to also protect the consumer from overexposure to other drainage contaminants.

Table 6. PUBLIC HEALTH CONCERNS ASSOCIATED WITH DRAINAGE WATER

Constituent	Drinking Water	Food Crops	Fish and Game	Occupational Exposures
Selenium	Some domestic wells in high-selenium areas may exceed the present EPA-recommended safe level of 10 ppb. However, EPA has proposed raising the level to 45 ppb. See the Federal Register, May 22, 1989; vol. 54, no. 97.	Field tests suggest that normal consumption of crops is unlikely to exceed recommended dietary allowances.	Consumption of fish and game from evaporation ponds and other contaminated areas that exceed safe levels should be restricted. In most other cases, normal consumption would be unlikely to cause toxicity.	Workers should restrict their exposure of direct contact with ele-vated levels of contaminants.
Molybdenum	Daily consumption of water from some domestic wells in high-molybdenum areas may exceed recommended health levels.	No standard defined.	No health-related data available.	Same as above.
Arsenic	Some domestic wells in high-arsenic areas may exceed recommended safe levels.	Regulatory standards are not developed.	Consumption of fish and game from evaporation ponds and other contaminated areas should be restricted.	Same as above.

Safety of Foraging

Preliminary investigation of persons who forage in the western side of the San Joaquin Valley has not shown evidence of overexposure to selenium. However, substantial difficulties exist in obtaining and evaluating survey data of this nature. Thus, it cannot be assumed that the population of foragers in this region is safe from exposure to potentially toxic concentrations of agricultural drainage-water contaminants. Persons who make a regular practice of foraging would likely be at similar or greater risk from exposure to drainage contaminants than would fishermen and hunters, who are likely to eat a more varied diet.

Occupational Exposures to Drainage Contaminants

Concentrations of selenium in the blood and urine of personnel monitored during closure and cleanup operations at Kesterson Reservoir were within normal limits. Thus, it seems unlikely that such occupational exposures at sites similarly contaminated would cause above-normal selenium levels. Occupational exposures to other contaminants have not been evaluated. Because occupational activity may result in significant contaminant exposures by inhalation or dermal routes rather than by ingestion, different methods for assessing exposure and adverse health effects may be warranted. As an example, certain chemical forms of chromium and arsenic (and several other metals) are known to cause respiratory cancers or other chronic pulmonary diseases when inhaled. No investigation has been made of specific risks to workers from inhalation or dermal exposures to contaminants found at sites where drainage water has accumulated and concentrated (such as evaporation ponds or treatment facilities). No evidence is available to suggest that health risks from these exposure routes would be elevated for the general population.

Safety of Drinking Water

Some ground-water sources of drinking water in westside San Joaquin Valley have concentrations of certain drainage constituents that can adversely affect human health, particularly when consumed over a long period. Arsenic, selenium, and nitrates have all been found in some domestic wells in the valley in concentrations that exceed current water-quality guidelines. With the exception of nitrates, these elevated concentrations are merely background levels that, in many cases, can be considered normal for these elements in the study area. Nonetheless, it is important to document when concentrations of substances exceed criteria set to protect an area's public health so that this information can be used in formulating drainage planning alternatives.

SOCIAL CONDITIONS

Community Infrastructure

While the economies of the communities on the western side of the San Joaquin Valley are primarily based on agriculture, these towns have sufficient infrastructure and other commercial resources to adapt to broad changes in the valley economy. A number of these communities are currently experiencing significant growth caused by residential-development overflow from coastal metropolitan areas. The rural character of these towns is being rapidly altered as they become more suburban, with residents commuting to cities on the eastern side of the San Joaquin Valley, to the Santa Clara Valley, and to the San Francisco Bay area. The direct dependence of westside community residents on agriculture is diminishing because a larger proportion is working in nonagricultural jobs.

The extent and rapidity of this suburbanization were not anticipated, and the emergence of zoning changes and subdivision development poses new problems for farms and wetlands in the surrounding areas. Given this continuing growth and high real estate prices in the metropolitan areas from which the newcomers originate, this transformation is expected to continue and even accelerate.

Farm Labor

Farm workers in the San Joaquin Valley are typically immigrants. Most come from Mexico, but significant numbers also come from Central America, Asia, and the Middle East. Only about ten percent of California's farm laborers were born and raised in the United States, and only about half of these are from California. Once they have arrived, a large minority of farm workers continues to migrate, either by moving back and forth between the U.S. and Mexico during the year or by following seasonal cropping patterns around the State. About 37 percent of the State's farm workers take part in one of these forms of continuing migration (Mines and Martin, 1986).

Crop specialization on valley farms has created seasonal employment for farm workers, who often secure a succession of short-term jobs to remain employed for most of the year. Although mechanization, new seeds, and improved production techniques are causing seasonality to decline, large numbers of seasonal farm workers are still employed in California (Martin, 1987).

Large numbers of farm workers are needed to tend and harvest crops on the westside San Joaquin Valley.

Farmers in the San Joaquin Valley depend more on hired labor than do farmers elsewhere in the U.S. Most farmers rely either on foremen to recruit laborers, usually without the direct involvement of top management, or on farm labor contractors, who hire farm workers and then contract with growers to provide a temporary workforce. The use of intermediaries to meet farm labor demands is becoming increasingly important in the State (Martin, 1987).

Issues surrounding farm workers' health and safety are growing in importance as concern for public health and environmental quality focus attention on farm chemical use and other management practices.

Water Supply and Drainage Management Organizations

Most agricultural water management processes in the San Joaquin Valley either originate in organizations or are strongly mediated by them. At the most general level, valley water management is institutionalized within organizations and networks of interorganizational relationships that structure linkages among water users, local water management organizations, and government agencies. Responsibility for water-use policy, planning, and day-to-day activities affecting drainage-related agricultural water management in the valley is dispersed among a large number of public and private water management organizations. Public water management involves water agencies, joint power authorities, hundreds of special districts, county governments, and a plethora of State and Federal administrative and regulatory agencies. Private water management is structured by incorporated and unincorporated river water associations and nonprofit mutual water companies, numerous agricultural corporations, family farms, and other groups (Coontz, 1989 and 1990a).

Water Management Networks

No single organization or network shapes overall water management or is found in all phases of water management throughout the valley. Valley water management is shaped by a variety of networks of private and public water management organizations. Network structures affecting agricultural water management at any given location and for specific kinds of water management activities are unique configurations of arrangements among various organizations. "Application" and "regulatory" networks are among the more important types affecting agricultural water management practices (Coontz, 1990b).

Application networks develop programs to provide professional and/or financial assistance to both on-farm and local organization water managers with the aim of improving water management practices and facilities. University researchers, Federal and State agencies, and contract consulting firms are the cornerstones of application networks.

Regulatory networks are composed of relationships among government regulatory agencies and various groups with interdependent interests tied to drainage management. Regulatory networks mediate conflicting interests by attempting to constrain and/or induce the discretionary activity of network participants so that they conform to a limited range of accepted actions and/or results. At least two qualitatively different regulatory networks, roughly corresponding to the valley's two hydrologic basins, shape regional regulatory strategies. These are a prescription-oriented network in the Tulare Lake Basin, which defines a range of acceptable actions to resolve drainage problems, and a performance-oriented network in the San Joaquin River Basin, which places more emphasis upon defining and meeting water-quality objectives.

Regional Institutional Spheres

In addition to organizations and networks, regional institutional spheres are important social structures that shape agricultural water management. They are configurations of unique political, economic, and social arrangements among and between water users and local water management organizations within a region. These spheres are more geographically restricted than regulatory networks and application networks. The principal institutional factors contributing to regionally specific variations that influence relationships among and between water managers within a region to outside organizations or government agencies include: (1) The degree to which formal or informal water management arrangements dominate, (2) the extent to which State or Federal agencies are integrated into water supply management, especially by the institutional structure of water rights and water contracts, (3) the degree to which agricultural water supply management and drainage management represent separate or integrated management structures, and (4) the relative importance of market relations in regional water management. The Drainage Program's five subareas roughly correspond to major regional institutional spheres (Coontz, 1990b).

THE EXISTING INSTITUTIONAL STRUCTURE

[Information in this section is summarized from a comprehensive study of water resources institutions sponsored by the Drainage Program (Thomas and Leighton-Schwartz, 1990).]

Water management institutions and laws that can both contribute to and help solve drainage and drainage-related problems are best described by illustrating the "chain of custody" of the water that ultimately results in problem drainage. Governing all water use in the State is the

Constitution of the State of California. The Constitution provides that all water within the State is the property of the people of California.

Though conceptually the physical resource remains a public asset, individuals may acquire an exclusive right to its use in the nature of a property right. But it is a highly qualified one. The State Water Resources Control Board oversees the allocation of these rights and the protection of water resources for the people of California. Private rights are conferred to those who exercise physical control over the water — be it surface or ground water — and put the water to a reasonable and beneficial use. Recognized beneficial uses pertinent to the drainage problem include irrigation, ground-water storage, and fish and wildlife uses. An "environmental water right" vests only where the water is diverted from its natural channel, as when it is applied to a refuge, but it does not vest when the water is left in the waterway.

Specifically, appropriative and riparian water rights (post-1914) are now administered through water permits issued by the State Board. Most of the irrigation water that eventually contributes to drainage is supplied through the Federal and State Water Projects as appropriative rights holders. However, appreciable amounts are supplied from ground-water pumping and local surface water. The Bureau of Reclamation holds water permits from the State Board entitling it to store, divert, and deliver water to the San Joaquin Valley through the Central Valley Project. The California Department of Water Resources holds permits for the water it develops and distributes to the valley through the State Water Project.

In protecting the public's water resources, the State Board retains authority to modify these permits to prevent the unreasonable use of water. However, unlike the diversion of surface water, there is no State-administered permit system for ground-water extraction. Nonetheless, the State Board's authority to prevent waste and unreasonable use of water comes not only from its contractual rights under the permits it issues, but also from the State Constitution, which does extend to the use of ground water. This authority is codified in State law and provides that the State Board, on its own motion or by petition of DWR or an aggrieved person, may prevent the unreasonable use of any surface or ground water.

In theory, this authority allows the State Board to require the Bureau of Reclamation and DWR, their contractors, or the end water user to take steps to reduce the generation of surface and subsurface drainage caused by excessive water application. In practice, however, the State Board has never used this power to address the drainage problem, and its exercise is sufficiently discretionary and judgmental that it is unlikely to provide a reliable solution to the overall problem.

Moving down a link in the chain of water management and use, the Bureau of Reclamation and DWR provide water to local water entities, including water agencies, water districts, irrigation districts, mutual water companies, and joint-powers authorities through contracts. These irrigation water service contracts vary significantly, but generally impose repayment, place, and manner-of-use restrictions on the districts. Pursuant to Federal contracts, which are effective for 40 years and automatically renewable, water entitlement is a stated maximum volume of firm water supply in acre-feet per year and currently priced between $3.50 per acre-foot and $19.31 per acre-foot. The price depends on the cost of facilities that were necessary to develop and deliver the water at the time of the contract and annual operation and maintenance costs. When these contracts are renewed, water charges will be based on annually adjusted cost-of-service rates. In 1990, Central Valley Project irrigation cost-of-service rates for the Delta-Mendota Canal and San Luis service areas varied between $13.58 and $23.01 per acre-foot (USBR, 1989). Water use is restricted to agriculture, and may be neither transferred to another nor used outside the district's boundaries without the approval of the Bureau of Reclamation.

Pursuant to State Contracts, which are effective for 75 years, the amount of total annual firm entitlement of State Water Project water that may be delivered in any month for agricultural use is limited to 18 percent of a contractor's annual entitlement amount. The price, which is based on the estimated actual operation, maintenance, energy, and capital recovery cost, is calculated annually. The 1990 price of State Water Project water in the San Joaquin Valley ranges from $32 per acre-foot to $67 per acre-foot (DWR, 1989). Transfers of SWP water must be approved by DWR. DWR seeks concurrence of all SWP contractors on transfers.

The final link in the chain is the sale of the water from the district to the grower. Generally, growers have pro rata shares or entitlement to the district's water, and pay for it at a rate designed to defray the costs of capital facilities, contract charges from project operations, and administrative expense. A few districts are currently experimenting with tiered or progressive water rates that are designed to induce conservation of water in excess of minimal evapotranspiration and leaching requirements. Some also impose rules on the recycling of tailwater. Generally, however, growers are left unfettered with regard to their decisions on how much water to apply, when, and in what manner. Some districts, most notably Westlands Water District, do provide informational programs to their growers on these variables, expressly designed to help the growers minimize drainage generation.

The regulatory institutions that govern the ultimate fate of drainage water in the valley's environment are predominantly State-created. The functions and dysfunctions of the regulatory system can be conveniently explained by referring to the public resources put at risk by drainage water. Existing regimes cover three of these resources: surface water, ground water, and wildlife.

The State Board protects both surface- and ground-water quality in the State through water-quality standards developed by Regional Water Quality Control Boards. Water-quality standards consist of "beneficial-use" designations and "water-quality objectives" which are established to protect the beneficial uses. These are set as part of regional or statewide water-quality control plans in quasi-legislative proceedings.

The Central Valley Regional Board has established a plan to protect San Joaquin basin surface water. The protection scheme, which is applicable to districts in the Northern and Grasslands subareas and the Westlands Water District, requires that drainers meet water-quality objectives for selenium, boron, and molybdenum. The Regional Board may revise the standards it established for selenium and boron because the Environmental Protection Agency, which has authority to oversee State water-quality protection, has determined that they do not protect beneficial uses. This scheme requires that drainers provide the Regional Board with plans, known as Drainage Operation Plans. The DOPs should include measures to reduce drainage and, hence, the amount of pollution discharged to the river.

Ground water is protected through State and Federal programs. Federal law provides little more than planning authority in protecting ground-water quality, but drives the protection of subsurface drinking water in California through standards established by the EPA. The primary focus of the Federal program is the prevention of contamination, rather than correction of existing pollution problems.

The more comprehensive ground-water protection schemes are those imposed by the State. California's ground-water strategy is to maintain ground-water quality at a level that satisfies present and future drinking water needs and other beneficial uses (such as irrigation) and, where feasible, to restore ground-water quality to these levels.

The State provides for two distinct kinds of ground-water protection standards: those relating to water quality and those relating to drinking water. Drinking-water standards address the quality of water at the point of delivery to consumers. Water-quality standards and drinking-water standards are established under two separate statutory schemes, administered by two different State agencies. The former is regulated by the State Board and the Regional Boards, and the latter is regulated by the California Department of Health Services. Additional protection is provided by the Department of Water Resources in its regulation of the design and construction of wells.

Protection of both wildlife and ground water from drainage disposed of in evaporation ponds has come largely from the State. DHS and the Central Valley Regional Board are the agencies charged with regulatory responsibilities. DHS basically deferred regulation of valley ponds to the Regional Board, which issues permits for the pond operations. Ponds that contain drainage water that exceeds State hazardous waste threshold limits may be operated under an exception to the State's land disposal ban. This exception expires in 1992.

The U.S. Fish and Wildlife Service is the principal Federal agency responsible for protecting and enhancing the nation's fish and wildlife resources, including preventing the unlawful take of migratory birds under the Migratory Bird Treaty Act. Its authority to protect migratory birds is broad. The agency may request Federal prosecution of evaporation pond owners and operators, which might lead to closure of ponds. To date, the USFWS has not prosecuted any San Joaquin Valley evaporation pond owners or operators.

The California Department of Fish and Game has similar authority under State laws. Under the State Fish and Game Code, DFG may seek action by the Attorney General against the impairment of fish and wildlife, including drainage-related impairment such as contamination of surface-water habitats from drainage discharges.

The fish and wildlife agencies may themselves be regulated by other Federal and State agencies. Specific to the drainage problem, USFWS and DFG are subject to the Regional Board's regulations for operations of their refuges and wildlife areas that discharge drainage water. The USFWS has prepared a Drainage Operations Plan for operation of the San Luis National Wildlife Refuge.